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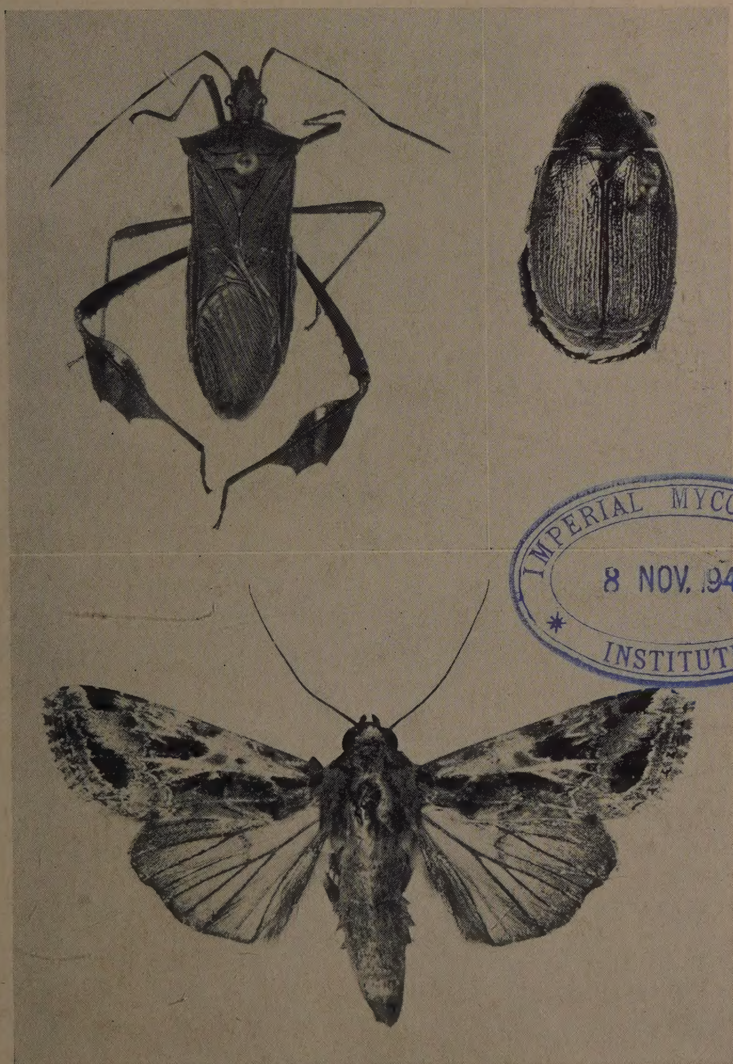
THE HAWAIIAN PLANTERS' RECORD



The Midway quarantine service, operated by the H.S.P.A., is protecting Hawaiian agriculture against these Guam insect pests which could easily reach here alive in trans-Pacific airplanes.

THIRD QUARTER 1940

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THE HAWAIIAN PLANTERS' RECORD

Vol. XLIV THIRD QUARTER 1940 No. 3

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

A Survey of the Insect Pests of Cultivated Plants in Guam:

We are fortunate in having a paper by O. H. Swezey presenting an account of Guam insects that are of economic importance and which might be destructive in Hawaii if they ever reached here by airplane or other agency. Many of the insects could be serious pests if they ever became establishd in the Islands. The knowledge supplied by Mr. Swezey enables us to be on guard against particular insects which we will now be able to recognize on sight. All of the insects discussed in his paper are represented in the excellent collection made by Mr. Swezey during 1936 and which now forms an important part of our extensive reference collection of foreign insect pests of sugar cane and other plants.

Distribution of Mineral Elements in Sugar Cane:

The relative concentrations of the various mineral elements in the leaves and different sections of the stalk are given. Results for the major elements were taken from chemical data, while the spectrograph was used to study the distribution of the minor and trace elements.

Some Effects of Cane Quality Produced by Different Soils:

Evidence which is presented indicates that different soils, even when cropped under identical environmental and cultural conditions, have produced canes with real differences in quality. Although the cause of such soil effects has not been determined it is suggested that the available nitrogen supply, which is influenced by the activity of micro-organisms, is probably the responsible factor.

Integration of Climatic and Physiologic Factors With Reference to the Production of Sugar Cane:

Climate has a very marked effect on the yields and quality of sugar cane produced under Island conditions. In this study cane was grown at Kailua and at

Waipio on Oahu. At these two places, soil moisture and soil nutrients were reasonably comparable, and yet the yield of sucrose at Kailua was less than half that at Waipio. This difference in yield is shown to be correlated with differences in sunlight and its absorption.

Since differences in atmospheric conditions are so marked, it seems clear that the fertilizer requirement of a crop will differ from area to area and from year to year. Therefore, in order to best integrate the growth of cane with the unpredictable weather, it is necessary to follow some index within the plant which will describe its reaction to the various elements of its surroundings.

In this study it was found that the well being of the plant was best reflected by the total sugar content of the sheaths of the young leaves. This is called the primary index. When this primary index is normal, maximum growth of good quality is being maintained. When the index is abnormal the secondary indices, particularly moisture, nitrogen, and temperature, will usually provide the clue to the difficulty. Other secondary indices are phosphorus and potassium. The advantage of using these running indices is that corrective measures can be applied while the crop is still in the field.

A Survey of the Insect Pests of Cultivated Plants in Guam

By O. H. Swezey

The preliminary report on an entomological survey of Guam, printed in the *Hawaiian Planters' Record*, XL, No. 4, pp. 307–314, 1936, was written while we were yet in Guam and had not had the opportunity of studying the material collected; hence, for many of the pests mentioned, names were not yet available for use. Then, too, more field information was gained before we departed from Guam. Now, after our collections have been studied by various experts who have worked on the families or groups with which they were respectively familiar, we have names for most of the crop pests, and it seems desirable that a more complete report should be offered. This will imply a revision of the preliminary report by the addition of the names that are now available, and further details and observations in the field. As before, the various crops are taken up one by one and their respective pests discussed.

This survey which occurred in 1936 was conducted under the auspices of the Hawaiian Sugar Planters' Association, the purpose being to study the insects of economic importance associated with the various crops grown in Guam, as well as to acquire information relative to insects affecting man and the domestic animals. As Guam is the most important station between the Philippines and Honolulu on the route of the Pan-American Airways across the Pacific, and as there was little knowledge available of the Guam insect fauna, it was deemed of significant importance to acquire as complete a knowledge as possible of this fauna, so as to know what undesirable insects might be likely to be carried as stowaways in the planes, and thus be forewarned as to what to look out for and to guard against introduction into Hawaii. Already, unknown insects were being found upon the inspection of planes arriving at Pearl Harbor, Oahu, and in spite of the system of fumigation of the planes an occasional insect was found which was not entirely dead. On account of this there was some concern lest unknown pests might survive and escape from the planes and succeed in becoming established and become destructive to sugar cane or other crops grown in Hawaii.

Through the efforts of Captain B. V. McCandlish, then Governor of Guam, transportation was obtained for us on the U. S. Army Transport *Grant*, leaving Honolulu, April 17, 1936. Our party consisted of myself and Mrs. Swezey and R. L. Usinger who was loaned under cooperation from the Bernice P. Bishop Museum. We arrived in Guam April 27. Mr. Usinger remained with us till July 6, while Mrs. Swezey and myself carried on till November 30 (7 months), then returned via the Philippines and the Orient.

As Guam is at such a distance and so little is known concerning it, except by those having had contact with it in one way or another, a brief description will be appropriate. As seen by reference to the map, it is really quite a good-sized island, instead of the mere dot as usually represented on maps of the Pacific Ocean. It is

MAP OF GUAM

The island is about 30 miles long; Agana is the capital. The portion of the island lying northeast of Agana is a limestone plateau 200 to 300 feet in elevation. The docks are at Piti, and a channel 2 miles long extends to the ship anchorage in outer part of Apra Harbor. At Sumay are located the Marine Barracks, Cable Station, and Pan-American Airways. The Clipper planes tie up at a floating dock about at the ''m'' in Sumay. Double lines indicate auto roads (100 miles); broken lines are trails; and double broken lines are poor roads.

nearly 30 miles in length, and is about one-third the size of Oahu—not quite so large as Molokai. It is nearer the equator than Hawaii, being about 13 degrees north, and located towards the Philippines, 3300 miles from Honolulu and 1500 miles from Manila. The town of Agana, about the middle of the western coast, is the capital and contains 12,000 people, which is a little over half of the population of the island. The native people are called Chamorros. In recent statistics they numbered 21,647 and there are about 1500 others, chiefly the naval colony, and the personnel of the Cable Station and the Pan-American Airways.

The northern half of the island is an elevated plateau of coral-reef origin which has been raised without tilting to its present position of about 300 feet elevation with a few regions as high as 600 feet. At the margin are precipitous jagged limestone cliffs 200 to 300 feet above the sea level, and there are no coastal villages. This area was originally covered with a tropical jungle containing several kinds of trees which grow to large size, such as banyan, breadfruit, ifil and joga. Much of this forest still remains, the rainfall being sufficient, even though there is little soil on top of the limestone which, however, is of a porous nature and allows for penetration of roots. Where areas have been found with soil enough for agricultural purposes there are clearings occupied by gardens and small farms and a few small settlements. An automobile road traverses about the middle and extends to the north point of the island accommodating the residents of this part of the island, many of the small farms being connected by bullock-cart trails through the jungle from a half mile to 3 or 4 miles from the main road. No streams are found in this part of the island.

The southern half of the island is of quite a different structure. There is a low mountain range of volcanic origin a little back from the western shore with a few peaks above a thousand feet, the highest peak towards the southern end being 1334 feet in elevation. Permanent streams are formed on both sides of this mountain range, those on the eastern slope being the larger, draining a considerable plateau area which is mainly grassland forested along the stream valleys. At the mouths of the valleys are located the coastal villages, at least a half dozen of some importance with a population ranging from a hundred to a thousand. An automobile road connects these villages, there being altogether 100 miles of automobile road on the island. Much of the farming is carried on in the valleys, especially rice growing. On the plateau region are some cattle ranches of considerable area.

The rainfall is about the same over the whole island, an average of about 90 inches annually, most of the rain occurring during the months from July to November. Rice is the only irrigated crop and it is grown during the time when the streams will supply the necessary amount of water. Planting is done in September and there is only one crop per year. Not enough rice is grown to supply the needs, importations being made from Japan.

The important crops are rice, corn, copra and many kinds of vegetables and fruits. The pests which we found on the various crops are herewith listed on their respective host plants.

Coconut

The coconut is the most important crop in Guam, the dried meat of the nuts being the copra of commerce. The previous year (1935), 1809 tons were exported

Fig. 1. Corn field planted amongst coconut trees.

Fig. 2. Copra drying in racks on the street at Inarajan.

at a value of $72,439.71. Copra is the only crop that is exported in any quantity, though in recent years there have been occasional shipments of avocados to Manila. The trees are growing in all parts of the island wherever clearings have been made, and in all the villages. Most of them have been planted, but some are volunteers. When a new clearing is made, coconut trees are planted among the remains of fallen trunks and stumps without waiting for a thorough clean-up. Much of the corn and vegetable crops are grown in the coconut groves. At present coconut trees are not severely injured by insects. The following attack them to some extent:

Aspidiotus destructor Sign.

This is the notorious coconut scale which so nearly ruined the coconut trees of Saipan island some years ago. It never became so serious on Guam, though some damage was reported in 1924 and 1925. However, it was soon brought under control by natural enemies such as chalcid parasites and a small black ladybeetle, *Telsimia nitida* Chapin.* The latter was so efficient that in 1928 the scale was reported controlled by it. In 1936, we found only occasional small colonies of the scale on coconut leaves, and never enough for significant injury. Similar small colonies of the scale were also found on leaves of avocado, mango, banana, grape, rose, citrus and jasmine. The little black ladybeetle was always present, indicating the cause of the scarcity of the scale. This ladybeetle was collected from bamboo infested with *Asterolecanium miliaris longum* (Green), and several hundred were shipped to Honolulu by clipper planes in November. They were liberated on plants infested with *Pinnaspis buxi,* and readily became established. They succeeded in controlling bad infestations of this scale on coconut leaves at Heeia, Oahu, and Hanalei, Kauai.

Lepidosaphes mcgregori Banks

Small colonies of this scale were occasionally found.

Pseudococcus cocotis (Mask.)

This mealybug was found to some slight extent on coconut, and also on a number of other trees and plants.

Acanthograeffea denticulata (Redten.)

This green phasmid or walking-stick insect was first recorded from Saipan of the Mariana Islands. We were shown coconut trees where this insect was said to have been very abundant at a previous time as evidenced by the very ragged leaves on which they had fed. However, we found only an occasional specimen, and no significant injury being done while we were there.

Agonoxena pyrogramma Meyr.

This is a small moth whose larvae feed on the under side of coconut leaves. They feed singly beneath a slight silken web and produce short, narrow, dead streaks where they have eaten off the under part of the leaf. From the appearance of the

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* This ladybeetle is the one for which the names *Cryptogonus orbiculus* and *Cryptogonus nigripennis* were used in the Guam Agricultural Experiment Station reports, and for which we used the name *Cryptogonus nigripennis* in reports here at the Experiment Station, until it was more recently determined by Dr. E. A. Chapin of the U. S. National Museum as his species *Telsimia nitida*, described from Guam in 1926.

leaves, these larvae must have been very numerous at times, but during our stay in Guam they were scarce, only an occasional larva was found and reared to maturity. The white cocoon spun by the full-grown larva is broad, oval, and flat, and spun on the upper surface of the leaf, very frequently on leaves of other plants and trees

Fig. 3. Coconut leaflets showing the dead streaks where eaten by the larvae of the tiny moth *Agonoxena pyrogramma.*

beneath coconut trees. A braconid parasite (*Macrocentrus pallidus* Full.) was sometimes reared from these cocoons.

This moth was described from the Solomon Islands on coconut, and I have found no record of it elsewhere, except that Fullaway recorded its work in Guam in 1911. A closely related species feeds on coconut in Fiji and Samoa.

Rhabdocnemis obscura (Boisd.)

The sugar cane weevil borer was found to some extent in stubs of cut off coconut leaves. Once an old cocoon was found in a coconut husk where the larva had fed. This same weevil was found similarly in nipa palm and betelnut palm. At the

Plaza, in Agana, a tall royal palm near the Government House was so severely injured by the larvae feeding in the crown among the unexpanded leaves that the tree was removed.

Diocalandra frumenti (Fabr.)

The larvae of this smaller coconut weevil were found feeding to some extent in stubs of cut off coconut leaves. They also feed in the stems of living leaves.

Bronthispa mariana Spaeth

While we were in Guam, some insect was reported killing the coconut trees on the neighboring island of Saipan. The people of Guam were alarmed lest this might be something that could spread to Guam. A Japanese boat (*Mariana Maru*) regularly made triangular trips—Guam to Yokohama, to Saipan, to Guam. The owner was persuaded to reverse the order of his route so as not to come directly from Saipan to Guam, a distance of only 120 miles, and thus lessen the opportunity for this insect to reach Guam. Through a Japanese merchant and the owner of the *Mariana Maru* we were able to obtain specimens of the destructive insect from Saipan, which turned out to be an unknown hispid beetle. Specimens were sent for study to the National Museum, where they had nothing like it. An entomologist in Europe eventually described it as a new species, naming it as above.

A large number of hispid beetles are known to attack the coconut in Pacific and Malayan regions, some being leafminers, and some living in the crown of the tree, feeding between the unfolded leaflets and causing greater injury to the tree than do the leafminers. This Saipan species is of the kind which attacks the crown of the tree. It is apparently a somewhat recent immigrant to Saipan, but it is not yet known from whence it came. The people of Guam will be fortunate if this beetle is kept out.

Figulus integricollis Thomson

This black lucanid beetle and its larvae were commonly found in rotten logs in Guam. We found it once in a dead leaf stem of coconut. It is a native beetle of Guam.

Necrobia rufipes (De Geer)

The widely distributed copra beetle was generally common. They were observed by hundreds on sacks of copra, stored in a warehouse at the docks awaiting shipment.

Scholastes aitapensis Malloch

Maggots of this fly feed in decaying coconuts. We did not find it common. Another species was also found, which has been described by the same author (Malloch), but not yet published.

Corn

Corn is the next most important crop in Guam. It is grown by all of the "ranchers," as the small farmers are called. It is largely used for human food, both green and ripe, as well as being a stock food. Two or three crops are grown annually, and it is found in some stage of growth at most any time.

Pyrausta nubilalis (Hübner)

The European corn borer was recorded from Guam in 1911 by Fullaway under the name *Pyrausta vastatrix,* given him by Mr. Schultze of the Bureau of Science,

Manila. It was later recognized as *nubilalis*, and increased till by 1925 it was reported as taking half the corn crop. Parasite introduction was begun in 1927. A tachinid fly introduced from Japan in 1931 was the only one to accomplish any control. This fly was first known as *Ceromasia lepida*, but later the name *Lydella stabulans* var. *grisescens* R. Deev. came into use on the mainland, where it was also introduced, and became established in the region around the western end of Lake Erie.

In 1936, I found that this tachinid fly was satisfactorily controlling the European corn borer in Guam. Usually, only a small percentage of injured stalks were to be found, and then the injury was not soon enough, or sufficient to prevent a well-formed ear. The caterpillars usually bored in the upper joints of the stalk, sometimes in the ear, and once they were found in the tassel. Usually about 50 per cent of the larvae found were parasitized by the tachinid—sometimes a much higher percentage. None of the larvae was found attacking any other plant than corn, though in the States it has been recorded attacking many kinds of plants.

Heliothis armigera (Hübner)

The corn earworm is the most injurious pest. About 5 per cent of the ears are attacked by the caterpillars, and sometimes a much higher percentage. Occasionally two or three caterpillars were found in one ear, and were always to be found on tobacco. No parasites were reared from any of them.

Prodenia litura (Fab.)

Caterpillars of this moth were occasionally found feeding on corn leaves. Several kinds of garden plants were more often attacked.

Marasmia trapezalis (Guen.)

The corn leafroller is nearly always present on young corn plants, the caterpillars rolling the tip portion of the leaf for protection while feeding within. If growing conditions are favorable the plant is hardly checked by the leafrollers. They become less common as the plant grows older. Sometimes a good percentage is parasitized by a braconid, *Apanteles guamensis* (Holm.), described from Guam in 1868.

Phytomyza spicata Malloch

This is a tiny black fly whose larvae feed very abundantly in the leaves of young corn plants. They produce narrow mines running longitudinally, often as many as a hundred per leaf. They are most numerous in the apical half of the leaf, causing early drying up and dying of the leaf, and giving the field a sickly appearance. No doubt they considerably check the early growth of the corn plants. Later on, the new leaves are less attacked, perhaps on account of apparent control of the leafminer by a tiny eulophid parasite which works in large numbers on the leafminer maggots. This leafminer was not previously recorded from Guam, and it has not yet been ascertained from whence it came, but it is known in Fiji and Samoa.

Peregrinus maidis (Ashm.)

The corn leafhopper is usually to be found, but not often in serious infestations. It is attended by a small green bug (*Cyrtorhinus lividipennis* Reuter) which feeds on the leafhopper eggs. It inserts its rostrum into the eggs which occur in the midrib of the corn leaf. Apparently this bug exercises a sufficient control of the leaf-

hopper. An attempt has been made to introduce this bug into Hawaii, and it has apparently become established. On one occasion an egg parasite (*Anagrus* sp.) issued from leafhopper eggs.

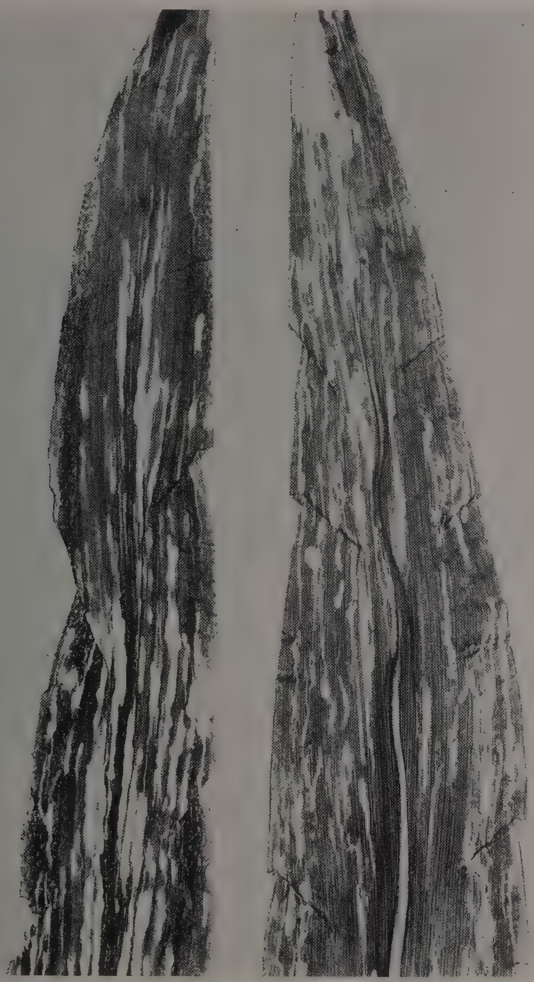

Fig. 4. Corn leaves showing the numerous mines of the maggots of *Phytomyza spicata* Malloch.

Aphis maidis Fitch

The corn aphis often causes bad infestations of the tassels when they are about to expand. Two large spotted ladybeetles [*Harmonia arcuata* (Fab.) and *Coelophora inaequalis* (Fab.)] become abundant and quickly reduce these infestations. Two other ladybeetles are of less importance as aphis feeders—*Coccinella transversalis* Fab., and *Anisolemnia mulsanti* (Montr.). The syrphid fly, *Ischiodon scutellaris* (Fab.), is also common, its greenish maggots feeding on the aphids. It in turn is parasitized; 38 chalcid parasites issued from a fly puparium collected on corn leaf.

They have not yet been determined. A few hundred of the large ladybeetle, *Harmonia arcuata,* were collected and sent to Honolulu for introduction, but apparently failed to become established.

Cicadulina bipunctella (Mats.)

An occasional specimen of this little cicadellid leafhopper was collected on corn. This little insect occurs on corn in Japan, Australia and Africa.

Grasshoppers

Two or three species of grasshoppers feed to some slight extent on corn leaves in Guam. These have not yet been definitely determined.

Holotrichia mindanaoana Brenske

This large brown scarabeid beetle is commonly called the banana beetle as it feeds sometimes very devastatingly on banana leaves, the feeding being nocturnal. The larvae, or grubs were found feeding on corn roots in a few places; sometimes a considerable injury being done, one large grub at the roots of a stool of corn being sufficient to kill it. It is an immigrant from the Philippines, and it may be the same insect referred to as *Lachnosterna* sp. whose white grubs were attacking pineapple roots (Report of Guam Experiment Station for 1930).

Anomala sulcatula Burm.

This is another immigrant from the Philippines, not previously reported by name. It is smaller than the preceding beetle, black, and also nocturnal in habit, though it is occasionally seen in the daytime. An adult beetle was collected from a corn leaf, and a few of the grubs were found at corn roots.

Calendra oryzae (Linn.)

The rice weevil is injurious to stored corn. Often much is destroyed when not properly stored, or treated to kill the weevils.

Miscellaneous:

A large number of different kinds of insects were collected from corn tassels, where they were either attracted by the pollen or honeydew from aphis infestation.

Diptera	Houseflies, numerous
	A native fruit fly: *Dacus* sp.
	Black anthomyid: *Ophyra chalcogaster* Wied.
	A large brown fly
	A broad-headed fly
	Tachinid
	2 kinds of sarcophagids
	Green dolichopodid
	Crane fly
Beetles	Bamboo beetle: *Chlorophorus annularis* (Fab.)
	Cerambycid beetle: *Prosoplus bankii* (Fab.)
	" " *Ropica* sp.
	" " *Sybra carolina* Mats.
	2 kinds of cucujids
	Nitidulids: *Carpophilus vittiger* Murray
Earwig	*Chelisoches morio* (Fab.)

Araecerus vieillardi (Montr.)

This anthribid was reared from dead corn stalk.

Ereunetis minuscula Walsm.

The larvae of this moth were found among dried corn husks.

Creontiades sp.

A plant bug found to a slight extent on corn.

Fig. 5. Rice field bordered by bananas, and with taro planted along the irrigation ditch.

Rice

Rice is a very important crop, being grown where land is favorably located for irrigation in the river valleys of the southern part of the island. Only one crop is grown per year, being planted in September during the rainy season, and ripening for harvesting during the following dry season. Not enough is grown to supply local needs, so imports from Japan make up the lack. A large number of insects were found in rice fields, some of them very injurious. Names have not been secured for all of them as yet.

Leptocorisa acuta (Thunb.)

The rice bug is a large long-legged bug which punctures and feeds on the soft, growing rice kernels causing a considerable loss. It has a wide distribution from India through the Malayan region. It was first reported in Guam in 1918 under the name *Leptocorisa varicornis,* a very closely related species also of wide distribution. When rice is not available it feeds similarly on some kinds of grasses, such as *Paspalum conjugatum.*

Creontiades sp.

This is a smaller bug which feeds on the leaves, but is not numerous enough for significant injury.

Nephotettix apicalis (Motsch.)

A green cicadellid leafhopper which is widely distributed in the Orient as a rice pest, and apparently had not been previously reported in Guam. We did not find it numerous enough for significant damage. This leafhopper was found in quantities on one occasion in a clipper plane when inspected on arrival at Pearl City. They must have flown into the plane from rice fields near Apra Harbor, while the plane was at anchor overnight in the harbor about a mile from the nearest rice fields. The planes are always tied up over night at a floating dock, fully illuminated while being serviced preparatory to an early morning departure, and night-flying insects may be attracted to the strong lights and readily gain access to the planes.

Nilaparvata lugens (Stal)

This is a delphacid leafhopper which is common, sometimes very abundant, and occasionally very destructive in the seedling plots. It is considerably parasitized by a dryinid, and its eggs are preyed upon by the small green bug *Cyrtorhinus lividipennis.* It sometimes comes in great numbers to lights. In one of the villages they were coming by hundreds to a kerosene lamp. The night we left Guam they were swarming at the electric lights on the dock at 10 p.m. A few were once found in a clipper plane arriving at Pearl City. It is a widely distributed rice pest in the Orient, and was apparently first reported in Guam in 1934 under the name *Megamelus.*

Grasshoppers

Several kinds of grasshoppers, not definitely determined yet, are found in rice fields. One of them feeds considerably on the heads when the kernels are still soft, thus causing considerable loss.

Susumia exigua (Butl.)

This is a small leafroller moth whose caterpillar rolls the leaf for protection. When young, there may be two or three in a single rolled leaf, but the larger caterpillars are singly per leaf. It is usually most abundant in the seedling plots, causing considerable injury to the young rice plants. The caterpillars are sometimes well parasitized by a braconid, *Apanteles guamensis;* on one occasion in an old field 66 per cent were parasitized. On the other hand, in a seedling plot where the leafrollers were numerous, no parasitism was found.

This leafroller was described from Japan, and I have not found it recorded elsewhere. Apparently it has been present in Guam for some time for in the Guam Experiment Station Report for 1918 there is mention of an unnamed "leaf folder" on rice whose habits as given agree with the present species.

Tineid

A tiny moth was reared from small caterpillars feeding in rice heads. They individually webbed together some branches of the rice heads, and fed on the growing grains. The species has not yet been determined.

Tatobotys biannulalis (Wlk.)

A pyralid moth whose larvae were found in large numbers feeding in decaying

leaves at base of old rice plants. There was no apparent injury to the living plant. The moth has a wide range from India and Malay Archipelago to Samoa and Society Islands. It was not previously recorded in Guam.

Fig. 6. Guam sugar mill, operated by carabao.

Fig. 7. Cauldrons in which cane juice is boiled down to sirup.

Spodoptera mauritia (Boisd.)

A world-wide distributed armyworm in the warmer regions. It was first recorded in Guam by Fullaway in 1911, he having reared it from Bermuda grass. Of late years it has sometimes invaded the rice seedling plots with disastrous results. The year we were in Guam may have been an exception, as there were very few reports of damage, and only two or three came under our observation. Little damage was done. Caterpillars were reared to maturity. The same moth was reared from grasslands, and collected at light. An ichneumonid parasite, *Echthromorpha conopleura* Krieger, was reared from the chrysalis and on one occasion 22 per cent of them were parasitized.

Melanitis leda (Linn.)

This butterfly is rated as a rice pest in India. We collected specimens in Guam, but did not find any caterpillars. Fullaway reared it from a caterpillar on corn in 1911.

Sugar Cane

Sugar cane is of little importance as a crop at the present time in Guam, less being grown than in former times. There are patches of 2 or 3 acres, and little attention is given to it. Some of it is grown only for eating. Mills for extracting the juice are of two vertical wooden rollers operated by a carabao sweep. Boiling of the juice is done in large open kettles fixed in a concrete furnace. The resulting molasses is largely made use of at a local distillery, or made into peanut candy for local consumption. There is a tendency toward a revival of cane growing with the distribution of "seed" from the Root Agricultural School Farm, where several standard varieties are growing which were received from Honolulu in 1935. Seed cane has been distributed from here at each time of cutting. The cane insects are mostly those generally distributed throughout the Pacific Islands.

Rhabdocnemis obscura (Boisd.)

The weevil borer is quite prevalent, being most injurious in those patches which are neglected and allowed to go for several years without replanting. At one time the tachinid fly (*Ceromasia sphenophori* Vill.) parasitic on the borer grub was established from colonies introduced from Honolulu in 1926, but the parasite has not maintained an existence there. We found nothing of it.

Perkinsiella thompsoni Muir

This leafhopper, closely related to the sugar cane leafhopper in Hawaii, was described from Guam from specimens collected by Fullaway in 1911. It was later collected more abundantly in Java, which could more likely be considered its home. We found it very scarce in Guam, never conspicuous, nor numerous enough to be injurious to the cane. Whenever eggs were found, they were heavily parasitized by a mymarid which is apparently the same species which was introduced from Queensland into Hawaii in 1904 (*Paranagrus optabilis* Perkins). An *Ootetrastichus* egg parasite is also present, for an exit hole was once found in a cane leaf, where a parasite had issued.

Trionymus sacchari (Ckll.)

The pink sugar cane mealybug was often found, but was not of much importance.

Pseudococcus boninsis Kuwana

The gray sugar cane mealybug was also found, and occasionally a heavily infested stool of sugar cane. The parasite *Aphycus terryi* Full. was reared from this mealybug, the same parasite which occurs on it in Hawaii. Several species of ants attended the mealybug infestations. The ladybeetle, *Cryptolaemus montrouzieri,* introduced from Honolulu in 1926, was occasionally found with the sugar cane mealybugs.

Pseudococcus brevipes (Ckll.)

The pineapple mealybug was also found occasionally on sugar cane.

Neomaskellia bergii (Sign.)

The sugar cane aleurodid was found in small colonies in a few places. In one place a single cane stool was found considerably infested. It was well attended by the "fire ant" *Solenopsis geminata rufa.* This is the first record of this aleurodid in Guam. It is distributed from Mauritius, Ceylon, Java, Philippines, Formosa, to Fiji and Samoa.

Aphis sacchari and the stalk mite were not observed by us in Guam.

Locusta danica (Linn.)

A large green grasshopper of wide distribution was generally found in grass regions, but was sometimes found on cane, producing a few ragged leaves.

Proutista moesta (Westw.)

This derbid leafhopper has been reported common on cane in the Philippines. We found only an occasional specimen on cane in Guam. It is no doubt a recent immigrant.

Cane Rust

In a few places there were slight infestations of this disease on cane leaves. Larvae of a cecidomyid midge were found feeding on the spores. The midge has not been determined yet.

Taro

Taro is quite generally grown, chiefly the upland varieties, there being sufficient rainfall everywhere for the purpose without special irrigation. The "wet" taro is grown in less amount, it being planted along ditches rather than in the pond method as in Hawaii. Taro was not found particularly damaged by insects in Guam, though a few kinds were sometimes present.

Prodenia litura (Fab.)

The eggs of this moth are deposited in clusters of several hundred on the under side of the leaf. The young larvae feed gregariously for awhile, then scatter to nibble here and there, causing dead spotting of the leaves. They mostly disappeared before becoming full grown, and I suspect that they are preyed upon by the *Polistes macaensis* wasps. These and two other kinds of wasps (*Icaria marginata* and *Rhynchium brunneum*) are very numerous, always on the search for caterpillars, and are undoubtedly of great importance in the control of this moth, other caterpillars, and the numerous kinds of leafrollers. This moth is of world-wide distribution in the Tropics. It was collected in Guam by Fullaway in 1911.

Megamelus proserpina Kirkaldy

The taro leafhopper is generally scarce on the upland varieties of taro, but the "wet" taro is usually found to be quite heavily infested, though not destructively injured by the leafhoppers. A dryinid parasite, *Haplogonatopus vitiensis*, is quite common. It in turn is parasitized by the hyperparasite *Echthrogonatopus exitiosus*, which diminishes its usefulness. No egg parasites of the taro leafhopper were found.

The taro leafhopper has a wide distribution, from the Philippines to Fiji and Samoa. It was first reported in Guam in 1924.

Lamenia caliginea (Stal)

This derbid leafhopper is quite widely distributed in the Pacific islands. It was previously collected in Guam by Fullaway in 1911, and described by Muir under the name *Thyrocephalus fullawayi*. It was later synonymized. We occasionally found it on taro, but it was not of economic importance.

Aphis gossypii Glover

The cotton aphis was found occasionally on taro leaves. Some were parasitized by a species of *Aphelinus*, and some were preyed upon by larvae of a syrphid fly.

Aleurodid

In a small patch of "wet" taro a few leaves were found infested with an aleurodid. No specimens were reared and no material was saved.

Banana

The banana is also grown very generally, but in a scattered way—not in mass production or field scale so far as I observed. Several kinds of insects damage banana plants more or less, most of them not usually severely.

Aspidiotus destructor Sign.

The coconut scale is found frequently in small colonies on banana leaves, a yellowish area indicating the presence of the colony. No severe injury is caused as the scale is so well controlled by a tiny black ladybeetle, *Telsimia nitida* Chapin.

Prodenia litura (Fab.)

Caterpillars of this moth do conspicuous damage to the leaves. The freshly hatched caterpillars feed at first near where the cluster of eggs was located on the under surface of the leaf. After a few days they scatter, and feed by nibbling the surface of the leaf here and there causing a spotting of the leaf which ultimately shortens its functional life. The large number of caterpillars which may be feeding on a single leaf is indicated by the number of eggs in the cluster which may have hatched on the leaf. The caterpillars which hatched from one unusually large egg cluster were counted, totalling 1224. The average cluster might contain about 300 to 400 eggs. Fortunately, most of the caterpillars disappear before getting much of a growth. I never found any full-grown caterpillars on banana leaves. Perhaps they are collected by wasps to feed their young.

On October 5, a colony of *Telenomus nawai* Ashm. was received from Honolulu, where it is a very effective parasite on eggs of *Laphygma exempta*. Experiments in breeding this parasite on *Prodenia* eggs were successful, the first genera-

tion appearing in ten days. Some were liberated, and a breeding supply was turned over to A. I. Cruz, at the Root Agricultural School, where breeding was continued and successive generations distributed for liberation in various districts of the Island. Later on, parasitized eggs were collected at several places, indicating that *Telenomus* had become established. It attacked the eggs of *Spodoptera mauritia* as well as those of *Prodenia.*

Holotrichia mindanaoana Brenske

This large brown scarabeid beetle was called the banana beetle on account of the extensive feeding which it sometimes does on banana leaves. The adult beetles feed at night time.

Cosmopolites sordidus (Germ.)

This large black weevil is the notorious banana weevil which is widely distributed in the tropics and was not previously recorded in Guam. We found it all over the island, the grubs feeding in base of old banana stems, and in some varieties they attacked and destroyed the new shoots; hence, it is quite a serious pest.

Polytus mellerborgi (Boh.)

This is a much smaller black weevil always to be found at the base of banana plants, usually the larvae feeding in the decaying corm, but sometimes in the living part as well. This beetle occurs in Hawaii, and is widely distributed on Pacific islands. It was not previously recorded from Guam.

Orthacanthacris sp.

A large grasshopper which was occasionally found feeding on banana leaves. The same species was also found on corn, cotton, tobacco, banyan, *Pipturus, Glochidion, Thespesia* and morning glory vines.

Citrus

Several kinds of citrus fruits are grown, such as orange, lemon, lime, grapefruit, tangerine and pomelo. All are attacked by the same kinds of insects.

Papilio xuthus Linn.

This swallowtail butterfly is somewhat of a recent immigrant in Guam, being recorded for the first time in 1925. It has a wide range in the Orient, Formosa, and also occurs in the Philippines. It is now very abundant in Guam. Sometimes the butterflies may be seen clustered by the hundreds at road pools or muddy spots, as shown by the accompanying photograph. The caterpillars feed on leaves of all kinds of citrus trees, but more especially on a related thorny shrub or small tree, *Triphasia trifoliata.* They were not numerous enough on orange, etc., to be considered a pest.

Phyllocnistis citrella Stainton

The citrus leafminer was first recorded in Guam in 1927, when it was so abundant as to seriously retard the growth of young seedlings, and to render mature trees unsightly. This leafminer is the larva of a tiny moth. The newly growing leaves are attacked causing a much crumpled and malformed growth—they eventually die prematurely. Hardly a leaf of new shoots escapes being injured. The effect on the leaves is shown in Fig. 9.

Fig. 8. Butterflies on moist roadway, showing abundance of this pest. The species is *Papilio xuthus* whose caterpillars feed on citrus leaves.

Fig. 9. Orange leaves with crumpled abnormal growth caused by the tiny leafminer moth larvae of *Phyllocnistis citrella.*

This insect has a wide range of distribution in the Orient, India to Japan; Philippines and Malay Archipelago, to Australia; also at Cape Town, South Africa.

Icerya purchasi Mask.

The cottony cushion scale is now well controlled by *Rodolia cardinalis* (Muls.), a ladybeetle introduced from Hawaii in 1926. No infestations were observed by us but bad infestations were reported in 1911 and 1929.

Aspidiotus destructor Sign. **Ferrisia virgata** (Ckll.)

These and one or two other scales were found to a slight extent on citrus. They are apparently well controlled by ladybeetles and parasites.

Fruit Fly

No citrus fruits were found infested by fruit flies, but a pretty new species of fruit fly was reared from native wild fruits; 2 species of *Ochrosia,* and parasites, *Opius longicaudatus* (Ashm.), were also reared.

Agrilus occipitalis (Esch.)

A small black buprestid beetle was common in dead twigs and branches of citrus. It is an immigrant from the Philippines, not previously recorded.

Stephanoderes insularis (Perkins)

A tiny scolytid beetle which was quite abundant in dead citrus twigs. It also occurs in Hawaii where it is found in dead twigs of several kinds of trees.

Nonymoides minimus Blair and **N. Swezeyi** Gress.

These cerambycid beetles were beaten from dead branches of citrus.

Corylophid

A small corylophid beetle was common in dead citrus twigs.

Gummosis

A disease of the bark that is more destructive than the insect pests. Several species of wood-boring beetles attack the trees when injured or dying from *gummosis.*

Pineapple

The pineapple is not grown extensively, only a few plants or small patches here and there. However, an attempt was made at one time to start a pineapple industry. About 30 acres were planted in 1929, but the project had a short life.

Pseudococcus brevipes (Ckll.)

The pineapple mealybug was the only pest which we observed on pineapple. It was generally scarce, but an occasional badly infested fruit was seen. Apparently it is well controlled by a small black ladybeetle with a reddish spot towards the apex of each elytron. This ladybeetle seems to be a species that occurs in Hawaii, introduced from the Philippines, not definitely named yet but known as *Nephus* sp. near *bipunctatus.* This ladybeetle was found feeding on *Ferrisia virgata* and other mealybugs on various plants. *Cryptolaemus montrouzieri* Muls., a larger ladybeetle, was introduced from Hawaii in 1926. We found it common, feeding on mealybugs and *Pulvinaria* on various plants.

Mango

Phytorus lineolatus Weise?

This is a Philippine chrysomelid beetle which first appeared in Guam about 1925 and increased rapidly till it often became very injurious to mango trees, causing almost complete defoliation. The beetles remain on the trees in the daytime. Besides feeding on mango, we found them feeding on coconut, breadfruit, grape, soursop, avocado, orange and 13 kinds of forest trees. Nothing was learned of its life history. At different times it was named for the Guam Experiment Station as *Phytorus pinguis* and *Phytorus puncticollis,* but it does not have the strong spine on front femur of *pinguis,* nor the distinct punctation of the thorax as in *puncticollis.* My material was determined by H. S. Barber who compared it with specimens in the Baker Philippine collection at the U. S. National Museum, which were determined *P. lineolatus* by Weise and marked with an (?).

Bombotelia jocosatrix (Guen.)

This moth was reared from a green measuring-worm caterpillar on mango. A case was reported of a mango tree having been defoliated by caterpillars; perhaps it may have been the same kind. This is another immigrant from the Philippines, not previously recorded.

Scale insects:

Aspidiotus destructor Sign., *Ceroplastes floridensis* Comst., *Lepidosaphes mcgregori* Banks and *Ischnaspis longirostris* (Sign.) occur on mango to some extent.

Breadfruit

The breadfruit is extensively planted in all the villages. A variety which has a somewhat irregular shaped fruit containing an abundance of seeds grows wild in the jungle. It is a large buttressed tree and is much used for timber. The living trees are remarkably free from insect injury. However, many insects are associated with logs, dead branches, fallen and rotten fruits, and the old staminate inflorescence.

Insects of Fallen Fruits

Drosophilid flies: 2 or more species.
Figitid: parasite of Drosophila.
Proctotrupid: parasite of Drosophila.
Nitidulid beetles:
- *Carpophilus vittiger* Murr.
- *Haptoncus ocularis* Fairm.
- *Urophorus humeralis* Fab.

Curculionid: *Anaballus amplicollis* (Fairm.)
Hydrophilid: *Dactylosternum abdominale* Fab. Predacious.
Staphylinids:
- *Thamiaraea insigniventris* Fairm. Predacious.
- *Homalota cribrum* (Fauv.) Predacious.
- *Phloeonomus hebridensis* Bern. Predacious.
- *Stilicopsis setigera* (Shp.)

Psychodid maggots.

Insects of Fallen Decaying Staminate Infloresence

Curculionid: *Anaballus amplicollis* (Fairm.)
Cerambycid: *Ropica* sp.
Aphodius lividus Oliv.
Ereunetis minuscula Walsm.
Larvae of tiny moth (undetermined).

Insects from Logs and Dead Branches

Large cerambycid beetle: *Dihammus marianarum* (Auriv.)
Small cerambycid beetle: *Sybra carolina* Mats.
Sclerodermus sp.: Parasite of *Dihammus* larvae.
Rhipicerid: *Callirhipis* sp. Larvae in dead sound wood.
Figulus integricollis Thoms. Larvae in rotten log.
Figulus liliputanus Westw. Larvae in rotten log.
Scolytid:
 Cryphalus swezeyi Schedl.
 Xyleborus testaceus (Walk.).
Tenebrionid: *Uloma cavicollis* Fairm.
Cucujid: a black species.
Ciid beetle: *Cis guamae* Zimm. (In press.)
Sciarid midge reared from larvae in rotten bark.
Termites:
 Neotermes papua Desneux, a large species.
 Prorhinotermes inopinatus Silv. (?), a small species.

Tobacco

Tobacco is grown only in occasional small patches.

Heliothis armigera (Hübn.)

Caterpillars of the corn earworm spoil many of the leaves, unless careful hand-picking is resorted to.

Prodenia litura (Fab.)

Caterpillars of this moth also feed on tobacco to a slight extent.

Engytatus tenuis Reut.

A plant bug that is common on tobacco, and also on tomato.

Grasshoppers

Two or three kinds of grasshoppers damaged the leaves to some extent.

Beans

Several kinds of beans are grown throughout the year, and are damaged by a number of insects.

Acrocercops sp.

A leafminer moth is very abundant. Its red larvae feed inside the leaves just beneath the upper epidermis which loosens and appears as a dead blotch. There may be several to a leaf, so that the whole upper surface appears dead. Before a

bean crop is finished, nearly all of the leaves become affected. A chalcid parasite destroys a few of the leafminer larvae.

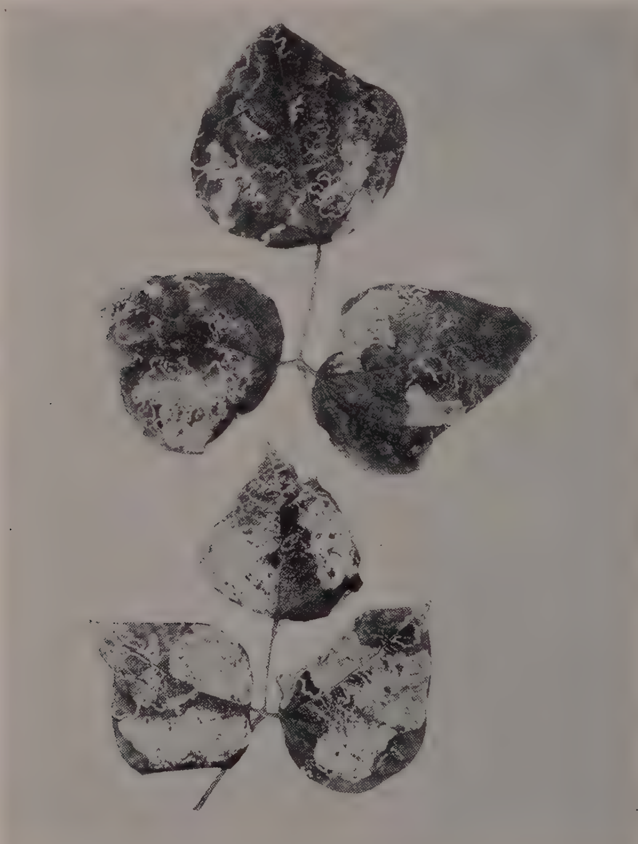

Fig. 10. Bean leaves destroyed by the bean leafminer moth, *Acrocercops* sp.

Nacoleia diemenalis (Guen.)

This is a leafroller moth with wide distribution in the tropics. It seems not to have been previously recorded in Guam. The larvae feed between webbed-together leaves, chiefly on pole beans.

Etiella zinckenella (Treit.)

This moth is a cosmopolitan pest in bean and pea pods. In Guam we found it only on one occasion, when the larvae were very abundant in pods of *Crotalaria saltiana* growing in a fallow corn field. Specimens were reared.

Tortricid leafroller

This is apparently an immigrant moth which is a general feeder, as I reared it from 21 different kinds of plants and trees, some of them being native trees. It

was once determined as the rose leafroller from America, but it has been pointed out to me that this was an error. The injury to beans is insignificant.

Plusia chalcites Esp.

The green looping caterpillars of this moth feed on bean leaves to a slight extent, as do also the looping caterpillars of a larger unidentified moth.

Argyroploce carpophaga (Walsm.)

This moth has been mistaken for a species in Hawaii whose larvae destroy a large proportion of the seeds of *Acacia koa.* I reared it a few times from beans in Guam. The larvae fed on the seeds in pods of both pole beans and lima beans. The larvae also destroy a large proportion of the seeds of such leguminous trees as *Pithecolobium dulce, Adenanthera pavonina, Poinciana regia,* and *Acacia farnesiana.* In two counts made of seeds in *Adenanthera* pods, 67 per cent and 77 per cent respectively of the seeds were destroyed. In a similar count, 21 per cent of *Poinciana* seeds were destroyed. *Acacia farnesiana* seeds were nearly all eaten.

Maruca testulalis (Geyer)

This is another bean pod pest of wide distribution. It occurs in Hawaii. The larvae were occasionally found in bean pods in Guam.

Cosmolyce boetica (Linn.)

The bean butterfly was collected in only two localities, where its larvae were in pods of *Crotalaria saltiana* and *C. quinquefolia.* The eggs were parasitized by a *Trichogramma.* We did not find it infesting beans.

Leptoglossus australis (Fab.)

This large black bug was sometimes found on bean vines.

Red Spiders

Bean leaves were often found infested with a leaf mite and Cecidomyid larvae were found feeding on the mites. Neither were determined.

Land Slugs

Both the large black species and the large gray species were abundant in Guam, and very destructive to bean seedlings, as well as those of other garden plants. I was shown a bean patch at Libugon Farm where the slugs had been collected at the rate of 500 per day, by being impaled on a sharp stick. A common practice is to make a line of salt around a garden plot as protection against inroads of slugs. Since the introduction of *Bufo marinus* to Guam in 1937, we have learned that the slugs have become greatly diminished in numbers.

Cabbage

At least three kinds of caterpillars feed to some extent on cabbage and related vegetables. They are *Prodenia litura* (Fab.), *Hellula undalis* (Fab.) and *Crocidolomia binotalis* Zell. The second one is the most destructive. The white cabbage butterfly was not found in Guam. The black slugs were particularly injurious to cabbages.

Cucumbers and Melons

Leptoglossus australis (Fab.)

This large black bug especially infests cucumber and melon vines. It also infests pumpkin vines and beans, and has been found feeding on fruits of eggplant and a passion vine weed, *Passiflora foetida,* and on sunflower heads.

Margaronia indica (Saund.)

Larvae of this pretty pyralid moth were occasionally found on leaves of cucumber, honeydew melon and pumpkin and were sometimes parasitized by *Cremastus flavo-orbitalis.*

Aphis gossypii Glover

The cotton aphis infests cucumbers and melons to some extent.

Chaetodacus cucurbitae (Coq.)

The melon fly was reared from cucumbers in a few regions and its maggots were also found in very small pumpkins. This pest has probably not been in Guam very long, as the principal cucumber growers have never reported any injury and, on being questioned, had no recollection of anything of the kind. It has probably arrived from the Philippines. It occurs from India to Formosa, and has been known in Hawaii for about 40 years.

Sweet Potato

Cylas formicarius (Fab.) and **Euscepes postfasciatus** (Fairm.)

The larvae of these two weevils bore into the vines and also work down into the tubers to some extent. They are more injurious in old or neglected fields. They were both reported by Fullaway in 1911.

Herse convolvuli (Linn.)

This morning glory hawk moth was common in Guam, its caterpillars feeding on various *Ipomoea* vines. I did not observe any on sweet potato vines, though it is known to feed on them—sweet potato being a species of *Ipomoea.* I reared parasites from eggs found on leaves of morning glory. Usually about half of the eggs found were parasitized. In one instance, 18 *Trichogramma* sp. issued from a single egg.

Eggplant

Aphis gossypii Glover

The cotton aphis often badly infests the leaves of eggplant.

Leptoglossus australis (Fab.)

The cucumber bug was found at one place feeding in large numbers on mature fruits of eggplant.

Carrot

Heterodera radicicola

The root knot nematode affects carrots badly, causing dwarfed and ill-shaped roots. It also affects turnips, radishes, beets, tomato roots, and probably many other plants.

Sunflower

Leptoglossus australis (Fab.)

In one place the cucumber bug was found very abundant in all stages on sunflower heads.

Anomala sulcatula Burm.

This large black scarabeid beetle has been found feeding on the seeds in sunflower heads. It is a common beetle coming to lights a good deal, and usually remaining hidden by daytime. The beetles were found by the dozen on the screen door one night at the Pan-American messroom at Sumay. Two specimens were once found in a Clipper plane when inspected on arrival at Pearl Harbor.

Grass Insects

Marasmia venilialis (Walker)

This is a leafroller moth related to the corn leafroller. It is very abundant and its larvae live on several kinds of grasses, rolling the leaf for a shelter.

Psara licarsisalis (Walker)

This is an abundant pyraustid moth whose caterpillars feed in turf in grasslands.

Grasshoppers

Several species of grasshoppers were common. They have not yet been fully determined.

Leafhoppers

Nine species of delphacid leafhoppers were collected from various grasses. One or more cicadellid leafhoppers were also obtained from grass.

Armyworms

Two species were found: *Cirphis loreyi* (Dup.) was reared from a caterpillar found on sword grass but was not common; and *Spodoptera mauritia* (Boisd.) which was common in grasslands, but not particularly injurious. The latter is the true *Spodoptera mauritia,* and is not the same species which we have in Hawaii and which has been known as *Spodoptera mauritia* for more than 40 years because of error in its original identification. Our species has recently been determined to be *Laphygma exempta,* a similar insect having much the range and habits of the true *Spodoptera mauritia.*

Miscellaneous

The guava does not thrive well in Guam on account of the larvae of a small tortricid moth (*Spilonota holotephras* Meyr.) which feed in the webbed-together new leaves, thus crippling the growth. This moth is so numerous and its work so effective that the guava is on the decline. Scarcely any fruit is produced, although I was told of an abundance of fruit a few years ago. From this, inference is made that this moth is a recent immigrant.

Terminalia catappa trees are always in a nearly defoliated condition on account of a tiny lepidopterous leafminer and another tiny moth whose larva lives in a case and feeds on the surface of the leaf. There may be dozens of these larvae per leaf. The beetles *Phytorus* and *Trigonops* also feed extensively on leaves of this tree; also *Selenothrips rubrocinctus.*

The caterpillars of a common large white butterfly, *Catopsilia crocale* (Cramer), feed on the golden shower and pink shower trees.

Hypolimnas anomala Wallace is a very abundant butterfly whose caterpillars feed gregariously on *Pipturus,* defoliating small trees, and in one region this had apparently been done by successive broods so that the trees were nearly dead.

Fig. 11. Leaf of *Terminalia catappa* showing injury by numerous tiny moth larvae living individually in tiny cases. Almost causes defoliation.

A small yellow butterfly, *Terias hecabe* (Linn.), was very abundant, and its caterpillars were defoliating a hedge of *Pithecolobium dulce* at the Naval Hospital.

Erythrina trees were found defoliated by caterpillars of the moths *Agathodes ostentalis* Geyer and *Othreis fullonia* (Clerck).

The terminal leaves of the hau tree (*pago* in Guam) were conspicuously rolled up by the caterpillars of *Sylepta derogata* (Fab.).

Fig. 12. Terminal foliage of *Heritiera littoralis* badly affected by a lepidopterous leafminer. The whole tree was similarly affected.

Termites

Three kinds of termites were found, and they were not particularly prevalent.

Cryptotermes hermsi Kirby

This species occurred in buildings, more particularly in old cabins.

Neotermes papua Desueux

This is a large termite found in logs in the forest.

Prorhinotermes inopinatus Silv.?

A small species also found in logs in the forest.

Fig. 13. Buttressed base of a breadfruit tree by a jungle roadside in the northern part of the island.

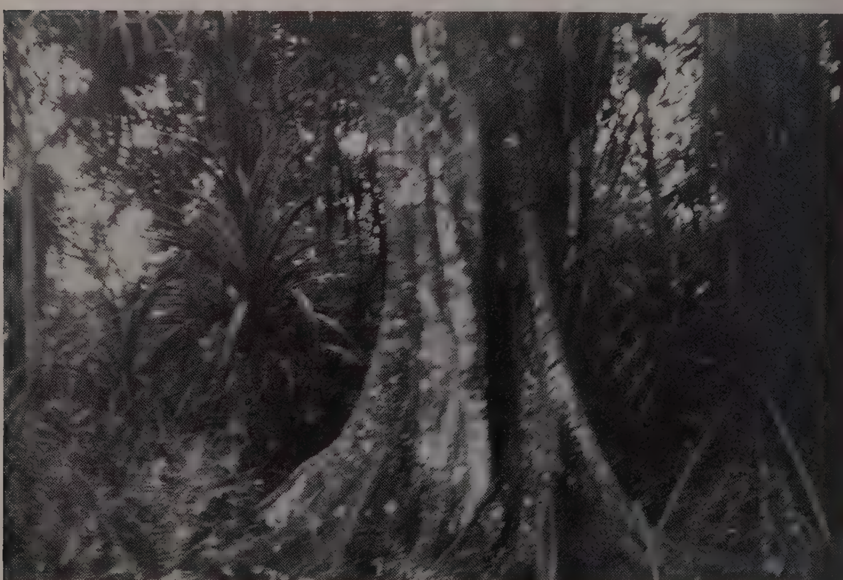

Fig. 14. Buttressed base of a joga tree in northern part of island and showing the characteristic growth. *Pandanus* is always plentiful.

Fig. 15. Banyan tree with fern masses and vines—characteristic jungle growth.

Forest Insects

Much information was obtained on other insects and on the insect fauna of the various forest trees and plants. Besides the leafminers and leafrollers above mentioned on cultivated plants, a large number of species of these moths has been reared from various forest trees. Other forest caterpillars have also been reared, producing a large assemblage of moths which have never been known or reported from Guam. Each is associated with its own special food plant. Much material has also been obtained in the other orders of insects. The bulk of this material has been worked up for publication by various entomologists, experts in their respective families or orders, and now awaits publication.

Mosquitoes

Two kinds of mosquitoes were previously known in Guam. Now the number has been increased to six, as follows:

Culex quinquefasciata Say

The common ubiquitous night mosquito was found breeding in many kinds of favorable locations, such as water barrels (gasoline drums), tin cans, stagnant pools, hog wallows, etc.

Culex sp.

A less common species which has not yet been definitely determined.

Aedes scutellaris var. **pseudoscutellaris** (Theobald)

We reared a few of this from a water-filled tree hollow in the forest, and water-

filled coconut shells on the ground. Later Mr. Cruz reared a large number from coconut hulls. It, as with the other species of *Aedes,* is a day mosquito.

Aedes aegypti (Linn.)

We did not observe this mosquito in 1936, but I found a few specimens among those of the preceding species reared by Mr. Cruz.

Aedes pandani Stone

This is by far the most abundant mosquito in Guam. It is the mosquito recorded in 1911 by Fullaway as *Stegomyia scutellaris,* of which he said: "The latter is very abundant in the forests and makes progress through the brush very unpleasant." Our experience was similar. We were always tormented by this day mosquito whenever out in the gardens, ranches or forests. Fortunately the effect of their bites is not so severe as it is with some other species of the genus. I reared this mosquito from larvae found in water held in the axils of *Pandanus* leaves, and in no other situation. There are several species of *Pandanus* in the forests and valleys of Guam, and they are abundant enough everywhere to provide ready breeding places for this mosquito. Furthermore, the rainfall is sufficient to maintain the water supply in the leaf axils. The larvae were always found when searched for in this situation.

Aedes oakleyi Stone

This species was reared abundantly by Mr. Oakley in 1938, from a water drum at the Root Agricultural School farm at Piti.

No malaria mosquitoes (*Anopheles*) have yet been found in Guam.

Housefly

Houseflies are very abundant about houses, in the forests and everywhere. Mostly they seem smaller than the usual housefly. They breed abundantly in cow dung and carabao dung, of which there is everywhere an abundance for the purpose. A parasite (*Spalangia cameroni*) was introduced for the housefly, from Honolulu in 1928. It became well established at the time, but now is rather scarce.

The hornfly, *Lyperosia irritans,* which is such a notorious cattle pest in Hawaii, was not found in Guam.

List of Pests in Guam Which Do Not Occur in Hawaii

Coconut:	*Aspidiotus destructor,*	Coconut scale.
	Pseudococcus cocotis,	Mealybug.
	Acanthograeffea denticulata,	Stick insect.
	Agonoxena pyrogramma,	Leaf moth.
	Diocalandra frumenti,	Coconut weevil.
	Scholastes aitapensis,	Ortalid fly.

Corn:	*Pyrausta nubilalis,*	European corn borer.
	Prodenia litura,	Egyptian cotton moth.
	Marasmia trapezalis,	Leafroller.
	Agromyzid,	Leafminer.
	Cicadulina bipunctella,	Cicadellid leafhopper.
	Grasshoppers, 2 or 3.	
	Holotrichia mindanaoana,	Root grub.
	Anomala sulcatula,	Root grub.
	Creontiades sp.	Plant bug.
Rice:	*Leptocorisa acuta,*	Rice bug.
	Creontiades sp.,	Plant bug.
	Nephotettix apicalis,	Cicadellid leafhopper.
	Nilaparvata lugens,	Delphacid leafhopper.
	Grasshoppers, 3 or 4.	
	Susumia exigua,	Leafroller.
	Tineid moth,	Larvae in heads.
	Tatobotys bianulalis,	Pyraustid.
	Spodoptera mauritia,	Armyworm.
	Melanitis leda,	Butterfly.
Sugar Cane:	*Perkinsiella thompsoni,*	Leafhopper.
	Neomaskellia bergii,	Aleurodid.
	Locusta danica,	Grasshopper.
	Proutista moesta,	Derbid leafhopper.
	Cane Rust,	Leaf disease.
Taro:	*Prodenia litura,*	Egyptian cotton moth.
	Lamenia caliginea	Derbid leafhopper.
	Aleurodid.	
Banana:	*Prodenia litura,*	Egyptian cotton moth.
	Aspidiotus destructor,	Coconut scale.
	Holotrichia mindanaoana,	Banana beetle.
	Cosmopolites sordidus,	Banana weevil.
	Orthacanthacris sp.,	Large grasshopper.
Citrus:	*Papilio xuthus,*	Swallowtail butterfly.
	Phyllocnistis citrella,	Leafminer.
	Aspidiotus destructor,	Coconut scale.
	Gummosis,	Bark disease.
Mango:	*Phytorus lineolatus* (?),	Leaf beetle.
	Bombotelia jocosatrix,	Looper moth.
	Aspidiotus destructor,	Coconut scale.
	Lepidosaphes mcgregori,	McGregor's scale.
	Ceroplastes floridensis,	Wax scale.
Tobacco:	*Prodenia litura,*	Plant bug.
	Engytatus tenuis,	
	Grasshoppers, 2 or 3.	Egyptian cotton moth.

Beans:	*Acrocercops* sp.,	Leafminer.
	Nacoleia diemensalis,	Leafroller.
	Etiella zinckenella,	Pod borer.
	Argyroploce carpophaga,	Pod borer.
	Tortricid leafroller,	
	Leptoglossus australis,	Cucumber bug.
Cucumber and Melons:	*Leptoglossus australis,*	Cucumber bug.
	Margaronia indica,	Leafroller.
Cabbage:	*Crocidolomia binotalis,*	Small moth.
Sweet Potato:	*Herse convolvuli,*	Hawk moth.

This is a total of about 50 species, about half of which were not previously reported, and several others not previously recorded by name.

A Spectrographic Study of the Distribution of Mineral Elements in Sugar Cane

By Stanley S. Ballard*

The plant physiologist, seeking an understanding of the particular functions of the various mineral elements, is aided by a knowledge of their distribution in the plant. This is important also to the agriculturist and to the soil chemist because it indicates the disposition of valuable nutrients at harvest; whether, as in the case of sugar cane, they are removed to the mill, or whether they remain on the field and become available to succeeding crops. At least one element, silicon, is believed to be associated with the resistance of sugar cane to attacks of certain insects and diseases. Hence, the degree to which it is present in susceptible tissues of the plant may be related to the relative immunity of a particular variety to such untoward conditions. Moreover, the plant pathologist finds that in the absence of the minute traces of certain of the "minor" elements normally present in plants, serious pathological conditions may occur. Therefore, to him also the distribution of the mineral elements in sugar cane is of especial interest.

The major nutrients such as potassium, phosphorus, and calcium are present in the cane plant in relatively large amounts and are readily and accurately determinable by the usual chemical methods. However, with some of the so-called minor elements which are present in sugar cane in exceedingly small quantities, chemical analysis becomes less precise, unless more time-consuming technics are employed. Fortunately, it is for work in this difficult field of agricultural analysis that the spectrograph, because of its extreme sensitivity to traces of the metallic elements, is especially well suited.

The present study affords an example of the use of chemical methods and spectrographic analysis as mutually supplementary analytical technics. This brief paper deals primarily with the adaptation of the spectrographic technic to the determination of the minor and incidental elements in sugar cane tissues of widely varying mineral content. Results for the major mineral elements were obtained chemically, and those for the trace metalic elements were obtained spectrographically.

Major Elements

Five parts of the cane plant were considered: green leaves, (designated hereafter as "GL"), dead leaves ("DL"), non-millable top, or growing point region ("GP"), green-leaf cane ("GC") and dry-leaf cane ("DC"). The chemical data for the major elements phosphorus, potassium, calcium, and silicon were taken from unpublished data obtained by A. S. Ayres in connection with Project D–1, "Basic Studies of the Cane Plant," and are presented here as a supplement to the

* Assistant Professor of Physics, University of Hawaii. The experimental data on which this paper are based were secured while the writer was Consultant in Spectroscopy, Chemistry Department, Experiment Station, H. S. P. A.

spectrographic data on the trace elements. The preparation and chemical analysis of this type of material have been described elsewhere (1), and will not be discussed here. Although silicon has not been proved to be an essential element for sugar cane, it is added to the list of major mineral nutrients because of its large occurrence in the plant. Table I gives the chemical results, with the various parts of the plant listed by symbol for each element, and arranged from left to right in order of decreasing concentration of the element in that part. The figures are in per cent (of the element) on the dry-weight basis.

TABLE I

DISTRIBUTION (AS DETERMINED CHEMICALLY) OF FIVE MAJOR ELEMENTS IN THE SUGAR CANE PLANT

Element	Order, and amounts (per cent, dry-weight basis)				
Phosphorus	GP	GL	GC	DC	DL
	.25	.19	.14	.11	.09
Potassium	GP	GL	DL	GC	DC
	2.0	1.8	.62	.60	.23
Calcium	DL	GL	GP	GC	DC
	.35	.22	.18	.07	.05
Magnesium*	GP	DL	GL	GC	DC
	.32	.29	.24	.23	.22
Silicon	DL	GL	GP	DC	GC
	2.6	1.8	.28	.20	.15

* The writer thanks F. Ray Van Brocklin for determining the magnesium content of the five samples.

Trace Elements

The materials used for the spectrographic analysis were prepared specially in order to avoid traces of contamination. A single stalk of 16-month H 109 cane was selected and removed from the Project D–1 Makiki plot, and a soil sample was taken from the immediate neighborhood of the stool. The various desired portions of material were cut from the plant specimen with a stainless steel knife, were washed thoroughly, cut into small chunks, and ashed in platinum dishes for 24 hours at 300° C. in order to concentrate the mineral fraction. The ash contents of different parts of the plant are known to vary considerably, and since this study dealt with the distribution of the elements in the dry plant material, rather than in the ash, the weights of ash to be compared spectrographically were taken so as to represent equal weights of oven-dry material. In Table II are listed the designations, identities, and ash weights of the various parts tested.

TABLE II

DESIGNATION, IDENTITY, AND ASH WEIGHT OF THE VARIOUS PARTS OF A SINGLE STALK OF SUGAR CANE ANALYZED SPECTROGRAPHICALLY

Designation	Identity	Weight of ash analyzed, milligrams
GL	Green leaves (blades)	6.2
DL	Dead leaves (blades)	6.2
GP	Non-millable top (Growing point and several inches below)	4.4
GC	Green-leaf cane	1.6
DC	4-month dry-leaf cane	1.0

These specimens, and a 2-mg. soil sample, were analyzed by the general methods previously described (2). Specific experimental data and conditions were: Exposures, 2 minutes at 8 amperes; conical-cavity graphite electrodes used, deep cone for samples GL and DL, and shallow cone for samples GP, GC and DC; arc focused on collimator lens; ⅛ aperture over collimator lens. This is not the highest sensitivity technic, but is the one that gives the best reproducibility. The entire analysis was run in duplicate, repeat spectrograms being taken some two weeks after running the originals. Analysis was made on the comparative basis, noting the relative order of concentration for the various parts, of each element encountered. It should be stated that with this semi-quantitative technic only rather large differences in amounts of an element present in various samples can be noted. Differences of a factor of 2 or 3 might very well escape notice. If more precise data are desired, quantitative spectroscopic methods (whose average error should not exceed 10 per cent) may be introduced. These would be considerably more laborious for an analysis involving so many elements.

The spectrograms were analyzed completely, so data on the major elements were obtained also. These were found to correlate fairly well with the chemical data of Table I. However, it was apparent that the spectrograph is no competitor of chemical methods for elements present in such large concentrations. (The spectrographic analyses, being conducted on *ash* samples, encountered these major elements present as 5 to 30 per cent of the total.)

The spectrographic results for the trace elements are presented in Table III. The symbol for the part of the plant containing the largest amount of the particular element is listed first, followed by the others in the order of decreasing amounts. Symbols are enclosed in parentheses to indicate approximately equal amounts present in those parts, and a dash indicates a large difference in amount between the parts whose symbols it separates. In addition to the known minor nutrients—iron, manganese, boron, and copper—data on all other elements encountered are given. Some of the latter may eventually be found to play a part in the physiology of the sugar cane plant. Table III also gives the estimated amounts of the various trace metallic elements found in the dry-leaf cane ash. These too are expressed on the dry-weight basis. They may be in error by as much as a factor of 5 or 10, as discussed elsewhere (2). However, they serve to indicate the approximate concentration of these elements in the stalk material.

TABLE III

DISTRIBUTION OF THE MINOR AND TRACE ELEMENTS IN THE SUGAR CANE PLANT, AND ESTIMATED ABSOLUTE PERCENTAGES (DRY-WEIGHT BASIS) FOR DRY-LEAF CANE

Element	Order of Abundance	Estimated per cent
Iron	(GP GC DC) GL DL	0.001
Manganese	DC — (GP GC) — GL	0.01
Boron	(all equal)	0.01
Copper	(all equal)	0.001
Aluminum	(GP GC DC)	0.001
Sodium	GL — DC (GP DL) GC	0.01
Strontium	DC — (GP GL)	0.0005
Barium	DC — GP	0.0005
Lead	GL	.....

The spectrographic sensitivity for the element zinc is not high, so zinc may have been present in trace quantities, and yet escaped detection. Additional trace elements which have been found in other sugar cane analyses, when more sensitive spectrographic methods were used, are titanium, chromium, nickel and tin.

The data of Table III show that the three parts of the stalk are approximately equal in iron content, while the content of this element in the green leaves was smaller, and that of the dead leaves smaller still. For manganese the order is dry-leaf cane; growing point and green-leaf cane; green leaves much weaker, and dead leaves too weak to be detected. No significant differences in concentration among the various parts of the plant could be noted for boron or copper, except that the copper lines for dry-leaf cane seemed a trifle weak. Equal traces of aluminum were found in all parts of the stalk, and none in the leaves. Sodium was strongest in the green leaves, weaker in the dry-leaf cane, weaker still in the growing point and dead leaves, and weakest in the green-leaf cane. Strontium and barium were found most concentrated in the dry-leaf cane. Traces of each of these elements were found in the growing point region, and a trace of strontium was noted in the green leaves. The trace of lead (estimated at 0.001 per cent, dry basis) in the green leaves is perplexing, particularly since lead was not found in the dry-leaf cane, which in a sense is the "thoroughfare" along which all minerals must move from the soil into the upper parts of the plant. Perhaps lead was an impurity in the electrodes or one resulting from contamination during preparation of the sample.

An examination of the soil spectrum showed all the elements of Table III to be present, with the exception of boron and lead. Boron is doubtless present in the soil in amount so small as to have escaped detection, and this affords an example of the ability of the plant to concentrate this minor nutrient.

Summary

This brief study presents data on the major and the trace mineral elements present in sugar cane, both as to absolute amount and as to distribution throughout the plant. The spectroscopic evidence shows the dry-leaf cane to contain the highest concentrations of several trace elements. The data suggest that the behavior of some major elements in migrating from dying leaves to the living portion of the plant is shared by iron, manganese, sodium and strontium. Chemical data on the distribution of five major elements, while not representing a new contribution, are presented in order to give a more complete picture.

The writer wishes to thank Mr. Ayres for permission to publish the chemical data, and for valuable assistance rendered throughout the course of this investigation.

Literature Cited

(1) Ayres, Arthur S., 1937. Absorption of mineral nutrients by sugar cane at successive stages of growth. The Hawaiian Planters' Record, 41:335–351.

(2) Ballard, Stanley S., 1940. The role of the spectrograph in the analysis of agricultural materials. The Hawaiian Planters' Record, 44:35–48.

Some Effects of Cane Quality Produced by Different Soils

By R. J. Borden and L. R. Smith

Interest in the possible effect which soils might have upon the quality of sugar cane has been stimulated by the results we have secured from our studies of the effect of climate upon cane growth (Project A–105—No. 43). In this skirmish test we have used two very different soil types potted in large concrete tubs and cropped comparatively under each of two distinct climatic environments. From the first harvest, we secured a significantly better quality or "yield per cent cane" from the cane that was grown on the Makiki soil (regardless of its environment), although this soil gave us less cane than the Manoa soil. A very similar result was obtained from the second crop on these two soils, but in the third crop, the Manoa soil produced not only more cane but in 6 out of 8 comparisons it had a somewhat better quality also. Unfortunately, rat damage to both the fourth and fifth crops makes their data somewhat unreliable for further statistical comparisons, but it would seem that the superior cane quality that has been secured on the Makiki soil was not again proved after the second crop.

TABLE I

AVERAGE GAINS AND LOSSES FOR MAKIKI OVER MANOA SOIL

Difference	First crop	Second crop	Third crop	Fourth crop	Fifth crop
In "yield % cane"	+ .90*	+ .84*	— .60	+ .20	+ .10
In lbs. cane	—10.60*	—8.28*	—7.48*	—9.01	—9.44
In lbs. sugar	— .78	— .34	— .99*	— .89	—1.10

* Only these differences are indicated statistically as being highly significant ones.

A study of possible reasons for this change of effect by the soil upon cane quality (yield per cent cane) brought out the fact that a rather large change had occurred in the soil pH, and although we are unwilling at this time to definitely attribute the cause to this factor, *per se,* we feel that it may warrant some consideration because of the many factors which may be either directly or indirectly related to soil acidity. In Table II we show just how this pH for the two soils has changed during the progress of this test.

TABLE II

CHANGES IN pH OF POTTED SOILS* COMPARATIVELY CROPPED

Soil	Initial pH	After first crop	After second crop	After third crop	After fourth crop	After fifth crop
Makiki	7.2	6.3	6.5	5.6	5.7	5.2
Manoa	5.4	5.3	5.0	4.8	4.9	4.7

* Average of 24 pots.

It must be kept in mind that these soils were potted in large concrete containers, have been cropped through five different seasons, and that the cane crops have been very generously fertilized with ammonium sulphate, superphosphate, and muriate of potash; also that each crop has left within its container a very large mass of old roots which subsequently have undergone decomposition therein. These factors undoubtedly have contributed to the increased soil acidity that has been measured.

If we set up the pH data from Table II, in terms of their equivalent "active acidity and alkalinity units,"* we can sense more clearly the relative degree in the changes that have taken place.

CORRESPONDING "ACTIVE ACIDITY (—) AND ALKALINITY (+) UNITS"

Soil	Initial	After first crop	After second crop	After third crop	After fourth crop	After fifth crop	Total increase (after 5 crops)
Makiki	+ 1	— 5	— 3	— 25	— 20	— 63	64 units
Manoa	—40	—50	—100	—160	—125	—200	160 units

Actually, the increase in acidity of the Makiki soil has not been as great as that of the Manoa soil under similar treatments. However, the inference is that during the first two crops, a more favorable pH (fewer active acidity units) of the Makiki soil was associated with better cane quality, and that since the second crop its increased acidity, together with the factors which are influenced by this acidity, have changed the favorable effect which this soil originally had upon cane quality.

Further Evidence: We have had another opportunity to note the effect of different soils upon cane quality, from the harvest results of the H 109 cane that was grown as the "controls" in our investigations concerned with minor element effects (Project A–105—No. 124). These plants, developed under controlled and identical conditions in Mitscherlich pots containing soils from 23 separate locations, have furnished additional evidence of some significant differences in cane quality that are most likely effects from the soil upon which the cane was grown. Again, searching for probable reasons for such effects, we find evidence of a fair correlation ($r = +.41 \mp .18$)† between the soil pH and the yield per cent cane, and a very significant correlation ($r = -.60 \mp .14$) between the yield per cent cane and the phosphate fixation index of these soils. Thus it would appear that the more acid soils with their associated higher phosphate-fixing powers had been responsible for the poorer cane qualities that were secured.

However, a study of the data in Table III will show that our answer is not quite so simple. The interesting relation between the yield per cent cane and the percentage of water in the millable cane ($r = -.84 \mp .06$) shows that the cane quality bore an inverse relationship to the water content of the cane that was grown. So our search continues for that soil factor which causes some canes to have a higher water content than others.

Dr. U. K. Das‡ found a higher water content in canes that had been heavily

* Soil reaction in relation to horticulture, American Horticultural Society, Bul. 4, 1926, by Edgar T. Wherry.

† All figures following a $\mp$ symbol in this paper are standard errors.

‡ The effect of nitrogen on cane yield and juice quality, The Hawaiian Planters' Record, 40:35–56, 1936.

fertilized with nitrogen, and if we may be allowed to use the per cent N of the crusher juice as a fair indication of the nitrogen content of the cane stalks, then we also find an excellent relationship ($r = +.83 \mp .07$) in our data between the nitrogen and water content of cane stalks.

If nitrogen was the real cause of these differences in quality, through its effect on the water content of the plant, then we may postulate about this nitrogen somewhat as follows: cultivated soils will vary considerably in their inherent total nitrogen content, in the nature and content of their organic matter, and in the nature, amount, and activity of their living organisms. Thus soils will vary in their power to make their nitrogen available. Similarly, some soils will "tie up" applied inorganic nitrogen fertilizer faster than others; some will release this tied-up nitrogen more slowly than others. And it is not unlikely that some soils also release some constituent that is taken into the plant and hinders the complete assimilation of such nitrogen as may be absorbed.

Furthermore such postulations have some direct connections with the soil pH and phosphate fixation indices which we found to be associated with our poorer cane qualities. Thus we generally find that these more acid soils have a much greater supply of organic matter and a higher total nitrogen content than the less acid soils, and under certain favorable conditions some of this natural supply of soil nitrogen would become available for plant absorption. We know that the activities and numbers of soil organisms are influenced by soil acidity: when active, they can tie up a considerable amount of any applied nitrogen fertilizer for as long as their supply of easily obtainable carbohydrate food lasts; but when sluggish, as in the less desirable conditions of the acid soils, more of the applied nitrogen fertilizer would be available for immediate plant absorption, and this might be "luxury absorption" if the application were a large one. Then too it is known that those acid soils, which also have the stronger phosphate-fixing properties, are also those with a high content of available iron and aluminum, and we suspect that plant metabolism which assimilates absorbed nitrogen might be subnormal in the presence of an excess of such substances.

Further study of Table III will show the existence of a positive correlation ($r = +.43 \mp .17$) which is fairly significant between the cane yields and its quality. On the other hand, a negative relationship is noted between this cane yield and both its nitrogen ($r = -.56 \mp .14$) and its water ($r = -.49 \mp .16$) contents. This would make it appear that either something has interfered with the complete utilization of the nitrogen absorbed, or that there had been a late release of soil nitrogen which the plant had not had time to metabolize.

TABLE III

AVERAGE OF 3 POTS (CHECK TREATMENTS) — VARIETY H 109 — HARVESTED IN JULY AT 12 MONTHS (PROJECT A–105—No. 124)

SUMMARY OF YIELDS

	Soil analyses — R. C. M.									
Soil No.	pH	% avail. N	% P_2O_5	% K_2O	P_2O_5 fixation	**Y%C**	Millable cane (lbs.)	% Water in cane	% N in crusher juice	Lbs. sugar
9	6.6	.0050	.032+	.012	50	**15.24**	5.07	69.1	.018	.77
7	6.9	.0020	.032+	.031	35	**15.01**	3.62*	71.1	.025	.54*
29	7.2	.0007	.008	.014	60	**14.93**	4.33	70.1	.023	.65
23	7.1	.0014	.006	.004	60	**14.93**	4.27	69.6	.028	.64
13	6.9	.0014	.020	.009	45	**14.88**	4.15	70.4	.029	.62*
21	5.8	.0043	.004	.003—	65	**14.57**	4.82	70.6	.035	.70
41	4.9	.0028	.006	.0028	90	**14.57**	4.48	70.7	.033*	.65
17	6.8	.0008	.004	.009	65	**14.56**	3.34	70.7	.032	.49
39	4.8	.0018	.012	.003—	80	**14.50**	5.67	70.6	.034	.82
11	7.0	.0023	.032+	.012	40	**14.50**	4.89	69.8	.013	.71
15	6.9	.0016	.004	.012	45	**14.44**	4.12	70.2	.024	.60
45	6.6	.0024	.010	.012	55	**14.43**	3.81*	70.0	.017	.56*
5	6.2	.0016	.024	.005	55	**14.30**	4.65	70.4	.025*	.66*
33	4.9	.0020	.008	.0028	90	**14.22**	4.95	71.6	.053	.70
43	5.0	.0037	.004	.003—	90	**14.15**	5.62	71.3	.027	.80
3	4.6	.0015	.0004	.005	75	**14.15**	4.43	71.1	.060	.63
31	4.8	.0015	.012	.003—	90	**13.90**	4.04	71.5	.041	.56
27	5.0	.0016	.004	.007	90	**13.89**	3.64	71.3	.075	.50
1	4.6	.0008	.0006	.0028	90	**13.83**	3.74	71.7	.068*	.52
37	4.7	.0026	.024	.003—	90	**13.70**	6.36	70.8	.026	.87
35	4.7	.0016	.004	.003—	90	**13.53**	4.09	71.2	.047	.55
25	6.2	.0008	.0006	.004	85	**12.38**	2.65	73.3	.109	.34
19	5.6	.0016	.0002	.0019	90	**12.30***	2.70*	73.3	.098*	.34*
Difference needed for significance: Odds of 19 to 1:						**.66**	.86	2.0	.012	.14
Odds of 99 to 1:						**.88**	1.14	2.7	.016	.18

* A possible deficiency of some "minor element" was indicated by significant effects from additions of a mixture of minor elements used in the "treated" companion pots.

A Uniformity Test: Our belief that these effects produced by different soils upon cane quality are real is strengthened by the results we secured from a Uniformity Test (Project A–105—No. 131) conducted under the same pot technique conditions which were used in securing the results recorded in Table III. From this test we have evidence that when the *same* soil is used, and identical cultural conditions are provided, differences in cane quality and yields between arbitrarily chosen groups containing only 3 pots each were not statistically significant. This can be quite clearly seen from the data which follow in Table IV.

TABLE IV

UNIFORMITY TEST—SEVEN COMPARABLE GROUPS OF 31–1389 CANE GROWN ON THE SAME SOIL (MANOA) UNDER IDENTICAL TREATMENT AND GROWING CONDITIONS (PROJECT A–105—NO. 131)

Averages of 3 Replicates

Group	Pot Nos.	**Yield % cane**	Lbs. cane	Lbs. sugar
4	22–24	**16.0**	5.37	.86
5	25–27	**15.8**	5.14	.81
6	28–30	**15.5**	5.25	.82
2	95–97	**15.2**	5.37	.81
7	31–33	**15.2**	4.90	.75
3	10–12	**15.1**	5.02	.76
1	92–94	**14.9**	5.20	.78

An analysis of variance of these data indicates that such differences in these Y%C, cane, and sugar figures as were measured, might quite easily be due to chance alone. Thus, these canes which were all grown on the *same* soil apparently did not differ among themselves in the characteristics measured.

The Present Study

With the foregoing background, we come to our study of the results from a skirmish test (Project A–105—No. 127) that was designed to continue this investigation of the effect of soil upon cane quality. A collection of 12 widely differing soil types (see Table V) was assembled and after thorough preparation these were potted in Mitscherlich containers and each planted with 2 distinctive cane varieties —31–1389 and D 1135. An identical environment with uniform fertilization, irrigation, and other cultural conditions was provided for 4 replicates of each variety on each soil during a 12-month growth period. All leachates were recovered and returned to the pots from which they came. The effects of these soils upon the cane quality and upon other crop measurements that were secured have been examined statistically from the basis of the 12 x 2 factorial setup that was established, and again we find some significant effects upon cane quality from different soils, as well as different effects upon several other measurements that were made. We propose to discuss these effects in some detail. Before we do this, however, it will be well to point out a few of the observations that were made while the crop was being grown:

(a) About half of the D 1135 stalks tasseled, but there were marked differences from different soils. On soil H4 every stalk produced a tassel. On H2 and O3 there was a 75 per cent tassel; on H1, K5, H8, and W9, half of the stalks tasseled, while on M6, M10, and H11 only 25 per cent of the stalks developed tassels. No tassels developed on cane grown on soils H7 or K12. The cause of these differences is not clear.

(b) None of the stalks of the variety 31–1389 tasseled.

(c) The variety 31–1389 grown on these soils showed marked differences in the amount of "leaf freckle" which developed. The cane on soils H7, W9, M10, and K12 showed no evidence of leaf freckle, but on K5, O3, and H2 it was ex-

TABLE V

DESCRIPTION OF SOILS USED IN PROJECT A–105—NO. 127

Soil No.	Identity	Elev. ft.	Origin	Color	Texture	Structure	Consistence	Vol. Wgt.
H1	Hawn. Ag. No. 44–2	2250	Residual	Dark gray-brown	Heavy loam	Granular	Mellow	.98
H2	Hakalau No. 23	850	Residual	Light yellow-brown	Gritty light clay loam	Crumb	Friable	.80
O3	Olaa No. 4–5	1500	Residual	Pale brown	Clay loam	Crumb	Friable	.70
H4	Hawn. Sugar No. 6–B	300	Residual	Dull brown-red	Silty clay loam	Granular	Dry: mellow Wet: soft and plastic	1.03
K5	Kilauea No. 17	350	Residual	Light brown	Heavy clay loam	Nut to crumb	Dry: mellow Wet: adhesive and cohesive	1.08
M6	Maui Ag. No. 91	800	Residual	Dark brown	Heavy silty clay loam	Crumb	Dry: mellow Wet: moderately plastic	1.09
H7	H. C. & S. No. M–9	50	Alluvial	Dark red-brown	Silty clay loam	Nut	Dry: friable Wet: soft and plastic	1.18
H8	Helemano Var. Sta.	600	Residual	Dark gray-brown	Heavy silty clay loam	Nut to crumb	Dry: friable Wet: moderately plastic	.91
W9	Waianae No. 4A	80	Alluvial	Dull gray-brown	Silty clay	Lump to nut	Dry: brittle Wet: moderately plastic	1.02
M10	Makiki No. 12	40	Alluvial	Dull gray-brown	Silty Clay loam	Nut	Dry: hard Wet: plastic and sticky	1.23
H11	Honolulu Plt. No. 66	160	Alluvial	Gray-brown	Heavy clay	Lump to sharply subangular nut	Dry: hard Wet: stiffly adhesive and cohesive	1.10
K12	Kahuku No. 13	20	Marine	Light gray-brown	Calcareous heavy clay loam	Nut to crumb	Dry: hard Wet: plastic and adhesive	1.01

tremely prevalent, and there was more on cane from H11, H8, and H4 than on H1 or M6. These observations appear to be quite nicely related to the per cent CaO in these soils, i.e., more freckle occurred on this variety when it was grown on soils that were low in available calcium.

Effect on Cane Quality:

TABLE VI

EFFECT OF SOILS ON YIELD PER CENT CANE

Soil No.	Average of all 8 pots	Average of 4 pots: 31–1389 only	Average of 4 pots: D 1135 only
H11	14.26	14.61	13.91
W9	13.86	13.45	14.27
H1	13.49	13.88	13.11
M10	13.37	13.02	13.71
K12	13.14	12.67	13.36
H2	13.14	13.02	13.23
H4	13.02	12.96	13.08
O3	12.74	13.18	12.30
H7	12.44	11.90	12.97
K5	12.16	13.00	11.32
H8	12.09	12.17	12.00
M6	11.92	11.88	11.96
Difference needed for:			
Odds of 19 to 1	1.14	*	*
Odds of 99 to 1	1.52		

* = Effect of interaction between soils and varieties is not significant.

It will be noted from the above that some significant effects were produced by different soils upon cane quality, i.e., yield per cent cane, and that these relative effects were apparently not influenced by the variety of cane that was grown, since the difference in quality between the two varieties was not significant (Avg. Y % C: for 31–1389 = 12.82; for D 1135 = 12.94).

In our harvesting technique, the green-leaf millable section of each stalk was separated from the dry-leaf section at the node which carried the lowest adhering green leaf, and carefully topped at the growing point. Thus our data can be broken down to study the effects of different soils upon the quality of both the green-leaf and the corresponding dry-leaf sections.

First, however, we have determined the ratio of the green weights of these two sections, and found what appears to be further evidence of soil effects.

TABLE VII

DRY-LEAF : GREEN-LEAF RATIOS AND YIELD PER CENT CANE

Soil No.	Dry-leaf section Avg. lbs. cane*	Green-leaf section Avg. lbs. cane*	Ratio of dry-leaf section / green-leaf section for both varieties	for 31–1389 only	for D 1135 only	Yield % cane* from dry-leaf section	from green-leaf section
H11	4.67	.54	8.7	8.7	8.7	14.91	8.58
W9	4.39	1.03	4.3	4.1	4.5	14.75	8.72
H1	4.89	.63	7.8	7.7	7.8	14.20	7.95
M10	4.42	.68	6.5	6.3	6.8	14.22	7.71
K12	2.98	.58	5.3	4.5	6.2	14.16	7.39
H2	4.14	.44	9.4	13.0	7.7	12.44	8.22
H4	4.65	.81	5.8	5.2	6.3	13.85	8.49
O3	4.31	.65	6.7	6.9	6.4	13.33	8.80
H7	2.63	.63	4.2	4.7	3.6	13.57	7.62
K5	4.54	.66	6.9	7.1	6.6	12.81	7.53
H8	3.78	1.01	3.7	3.6	3.9	13.18	7.94
M6	3.57	.72	5.0	4.7	5.3	12.75	7.36
Diff. needed for odds of:							
19 to 1	.40	.14	...	...	...	1.14	ns
99 to 1	.53	.19	...	...	...	1.52	

* Averages of 8 pots—both varieties.
ns = treatment effect is not significant.

Significant differences between weights within both the dry-leaf and the green-leaf sections are apparent. Interactions between soils and varieties, although significant, were greatly overshadowed by their separate effects.

We are not at all sure of a cause for these widely different ratios of dry-leaf to green-leaf sections, nor what their effect was. When they were first noted, we thought that they might be a reason for the differences in cane quality but the correlation coefficient ($r = + .36 \mp .18$) between the yield per cent cane and the "grean-leaf : dry-leaf ratio" does not warrant any too great confidence in such an assumption.

Only in the dry-leaf section do we find some real differences in cane quality that have apparently been produced by the different soils; the differences between soils for the Y % C figures from the green-leaf sections are most likely due to chance.

A few specific interactions were indicated in the dry-leaf sections only. Chief among these was a better quality for D 1135 than for 31–1389 on soil No. H2. and the reverse, i.e., 31–1389 with better quality than D 1135 on soil No. K5.

Incidentally, we note that in the dry-leaf section the quality of the two varieties was not significantly different, but in the green-leaf section the quality of D 1135 was definitely superior to that of 31–1389:

Variety	Yield per cent cane: Dry-leaf section	Yield per cent cane: Green-leaf section
31–1389	13.85	6.95
D 1135	13.51	9.12
Difference needed for odds of:		
19 to 1	.46	.48
99 to 1	.61	.64

(About half of the D 1135 stalks had tasseled, which may partly account for this difference in quality of the green-leaf section.)

Good reasons for these different influences on cane quality by different soils are not as easy to find in this study as in the studies we discussed earlier. There may possibly be an interaction between soils and their cane yields which is responsible for the influence of the soil upon the quality of the 31–1389 cane variety, since there is a significant correlation ($r = + .42 \mp .12$) between the cane yields and their quality from 48 pots of this variety; but this can hardly be the reason for the effect of the soil upon the quality of D 1135, for with this variety the correlation between cane yield and its quality ($r = + .20 \mp .14$) is clearly not a significant one.

Table VIII has been arranged like Table III, i.e., the yield per cent cane figures appear in a descending order, with other corresponding pertinent measurements recorded for study of their several relationships. Since no significant differences in yield per cent cane were found between the two varieties, the arrangement in Table VIII disregards the variety differential (although the varieties have been indicated). An inspection of these data fails to reveal the same evidence of correlation between the yield per cent cane and such factors as soil pH, phosphate fixation, per cent water in cane, and per cent nitrogen in the crusher juice, that we found in our previous study (No. 124), and which we thought might be associated causes of the cane quality differences from different soils. Thus we have measured the following correlations, none of which is significant however:

(1)	Between Y % C and pH	$r = + .04 \mp .20$
	" P_2O_5 fixation	$r = - .18 \mp .20$
	" % water in cane	$r = + .23 \mp .19$
	" % N in juice	$r = - .36 \mp .18$
	" % N in soil	$r = - .03 \mp .20$
(2)	Between cane yield and Y % C	$r = + .28 \mp .19$
	" % N in juice	$r = - .21 \mp .19$
	" % N in soil	$r = + .03 \mp .20$
	" % water in cane	$r = + .04 \mp .20$
(3)	Between total dry matter and Y % C	$r = + .33 \mp .18$
(4)	Between % N in soil and % N in juice	$r = + .21 \mp .19$

Valid reasons for the absence of a favorable relationship between the above factors in this test (No. 127), as compared with the apparent presence of significant correlations between similar factors in a previous test (No. 124), will be difficult to identify. The twelve soils used in test No. 127 were all from different sources than the 23 soils used in test No. 124. The cane varieties grown on these soils were also different. The experimental errors in No. 127 were quite different from those associated with No. 124, being much higher for yield per cent cane but considerably lower for cane yields.

TABLE VIII

AVERAGES OF 4 REPLICATES—VARIETIES 31-1389 AND D 1135—HARVESTED IN DECEMBER AT 12 MONTHS
(PROJECT A-105—NO. 127)

SUMMARY OF YIELDS

Soil No.	Variety	Soil pH	% avail. N in soil	% P_2O_5 in soil	% K_2O in soil	% CaO in soil	Soil P_2O_5 fix.	**Y % C**	Total dry wt.* (gms.)	Weight of cane stalks only (lbs.)	% water in cane	% N in crusher juice	Lbs. sugar
H 11	31-1389	6.2	.0013	.005	.011	.29	45	**14.61**	1193	5.45	71.6	.035	.80
W 9	D 1135	7.6	.0006	.032+	.003—	.42	40	**14.27**	1018	5.03	68.6	.025	.72
H 11	D 1135	6.2	.0013	.005	.011	.29	45	**13.91**	1082	4.97	71.6	.025	.69
H 1	31-1389	5.6	.0025	.028	.011	.11	65	**13.88**	1177	5.55	70.3	.028	.77
M 10	D 1135	7.2	.0018	.032+	.037	.42	40	**13.71**	1051	4.98	70.9	.032	.68
W 9	31-1389	7.6	.0006	.032+	.003—	.42	40	**13.45**	1252	5.82	66.2	.035	.78
K 12	D 1135	8.2	.0009	.0012	.009	.42	40	**13.36**	765	3.07	70.4	.030	.41
H 2	D 1135	4.9	.0012	.028	.003—	.009—	90	**13.23**	1005	4.96	69.6	.020	.66
O 3	31-1389	5.2	.0017	.006	.003—	.009—	90	**13.18**	1040	4.80	70.3	.053	.63
H 1	D 1135	5.6	.0025	.028	.011	.11	65	**13.11**	1090	5.51	70.6	.017	.72
H 4	D 1135	6.3	.0011	.0021	.003—	.11	75	**13.08**	1076	3.08	68.1	.017	.70
H 2	31-1389	4.9	.0012	.028	.003—	.009—	90	**13.02**	877	4.20	74.7	.041	.56
M 10	31-1389	7.2	.0018	.032+	.037	.42	40	**13.02**	1122	5.21	71.0	.029	.68
K 5	31-1389	5.4	.0115	.0015	.012	.036	50	**13.00**	1275	5.77	69.1	.034	.75
H 7	D 1135	7.7	.0053	.022	.031	.42	40	**12.97**	608	2.61	67.9	.045	.34
H 4	31-1389	6.3	.0011	.0021	.003—	.11	75	**12.96**	1174	5.60	68.4	.023	.72
K 12	31-1389	8.2	.0009	.0012	.009	.42	40	**12.67**	985	4.06	69.1	.028	.53
O 3	D 1135	5.2	.0017	.006	.003—	.009—	90	**12.30**	1019	5.12	69.9	.040	.63
H 8	31-1389	5.4	.0063	.007	.012	.072	55	**12.17**	1148	5.73	66.8	.034	.70
H 8	D 1135	5.4	.0063	.007	.012	.072	55	**12.00**	808	3.86	68.2	.029	.47
M 6	D 1135	6.4	.0018	.014	.018	.11	55	**11.96**	760	4.06	71.6	.037	.49
H 7	31-1389	7.7	.0053	.022	.031	.42	40	**11.90**	850	3.92	69.1	.056	.47
M 6	31-1389	6.4	.0018	.014	.018	.11	55	**11.88**	919	4.52	70.4	.045	.54
K 5	D 1135	5.4	.0115	.0015	.012	.036	50	**11.32**	906	4.62	71.4	.035	.53
Difference needed for significance: Odds of 19 to 1:								1.62	109	.64	2.2	.009	.11
Odds of 99 to 1:								2.14	145	.86	3.0	.012	.15

* Includes trash, tops, bagasse, and solids in juice.

This test, No. 127, was started in December whereas No. 124 was started in July—thus the growing seasons were quite different. Not only was the 12-month crop of cane in No. 124 produced under a greater number of "day-degrees" than the canes in No. 127, but the distribution of this growth factor during the growing periods for the two tests was dissimilar, as may be seen from the following:

	Total Day-Degrees	
Period of growth	Test No. 124	Test No. 127
First 3 months	1452	1007
Second 3 months	1295	961
Third 3 months	972	1262
Fourth 3 months	1002	1186
Total for 12 months	4721	4416

Under the environmental conditions which exist for pot culture studies, microorganic activity should have been at its maximum considerably earlier in No. 124, and the available carbohydrate supply for the soil organisms was probably exhausted from the small pot of soil within a few months. This condition would probably not have come about in No. 127 until the crop was well under way, and in such a case it is reasonable to assume that the later applications* of the nitrogen fertilizer were probably still being shared with the soil organisms and so did not all get up into the plant. Our investigational facilities for this study did not allow us to make investigations of soil microorganic activity, or of carbon-nitrogen relationships in these soils, so our assumption was not verified. But, we do feel that the "available" nitrogen supply has in some way been responsible for the different effects which these soils have had upon cane quality, and that such other correlations as are found, exist in connection with the manner in which they may influence this "available" nitrogen supply.

* In both tests, the total N fertilizer allowance for the crops was divided into 8 equal doses for monthly application during the first 8 months of growth. This procedure has been found to be good practice in pot culture studies.

Other Effects of Soils Upon Yields:

TABLE IX

DRY WEIGHTS, MILLABLE CANE, AND SUGAR

	Total dry wgt.* (grms.)				On millable cane (lbs.)				On sugar (lbs.)		
Soil No.	Avg. of all 8 pots	Avg. of 4 pots 31–1389	Avg. of 4 pots D 1135	Soil No.	Avg. of all 8 pots	Avg. of 4 pots 31–1389	Avg. of 4 pots D 1135	Soil No.	Avg. of all 8 pots	Avg. of 4 pots 31–1389	Avg. of 4 pots D 1135
H11	1137	1193	1082	H1	5.53	5.55	5.51	W9	.75	.78	.72
W9	1135	1252	1018	H4	5.47	5.60	5.33	H1	.75	.77	.72
H1	1133	1177	1090	W9	5.42	5.82	5.03	H11	.75	.80	.69
H4	1125	1174	1076	H11	5.21	5.45	4.97	H4	.71	.72	.70
K5	1091	1275	906	K5	5.19	5.77	4.62	M10	.68	.68	.68
M10	1086	1122	1051	M10	5.09	5.21	4.98	K5	.64	.75	.53
O3	1030	1040	1019	O3	4.96	4.80	5.12	O3	.63	.63	.63
H8	977	1122	808	H8	4.79	5.73	3.86	H2	.61	.56	.66
H2	941	877	1005	H2	4.58	4.20	4.96	H8	.58	.70	.47
K12	875	985	765	M6	4.29	4.52	4.06	M6	.51	.54	.49
M6	839	919	760	K12	3.57	4.06	3.07	K12	.47	.53	.41
H7	729	850	608	H7	3.26	3.92	2.61	H7	.40	.47	.34
Diff. needed for odds of:											
19 to 1	77	109	109		.45	†	†		.08	.11	.11
99 to 1	103	145	145		.60	†	†		.11	.15	.15

* Includes trash, tops, bagasse, and solids in juice.

† Effect of interaction between soils and varieties is not significant.

Dry Weights: In general there were some highly significant differences between the total dry weights harvested from these 12 soils.

Although the variety 31–1389 produced 16 per cent more total dry weight than D 1135 there is rather convincing evidence of an interaction between soils and varieties which may be summed up as follows:

(a) the two varieties were apparently not affected differently on soils Nos. H1, O3, H4, or M10;

(b) on soil No. H2 only, D 1135 was 15 per cent better than 31–1389;

(c) the variety 31–1389 was probably 10 per cent better than D 1135 on soil No. H11, and definitely superior to D 1135 by 23 per cent on No. W9, by 40 per cent on No. K5, by 39 per cent on No. H8, by 30 per cent on No. K12, by 68 per cent on No. M6, and by 40 per cent on No. H7.

Cane: Differences in their ability to produce millable cane among several of these soils are clearly significant, and the effect of soil was apparently quite similar with both varieties, although 31–1389 produced 17 per cent more millable cane than D 1135. This absence of an interaction between soils and varieties upon the millable cane does not conform to the definite interaction of these two factors which we noted with the total dry weight. Hence it is quite likely that those significant interactions which were concerned with total dry weight were from the effects on the non-millable parts of the crop, i.e., on the tops and sucker growth which might have been potential millable cane if a longer growing period had been allowed.

Sugar: Some of these soils have produced significantly more sugar than others, but this effect has been modified by the varieties on several of the soils. For instance, the variety 31–1389 was a better sugar producer than D 1135 by 43 per cent on soil No. K5, by 50 per cent on No. H8, and by 40 per cent on No. H7, and also probably better by 30 per cent on soil No. K12. On the other hand, although all 48 pots of 31–1389 produced 12 per cent more sugar than D 1135, the production of sugar was not significantly different on soils Nos. H1, H2, O3, H4, M6, W9, or M10, for these two varieties.

Other Effects of Soils Upon Crusher Juice Analyses:

TABLE X

ANALYSES OF CRUSHER JUICES

	On % N in juice				On % P_2O_5 in juice				On % K_2O in juice		
Soil No.	Avg. of all 8 pots	Avg. of 4 pots 31–1389	Avg. of 4 pots D 1135	Soil No.	Avg. of all 8 pots	Avg. of 4 pots 31–1389	Avg. of 4 pots D 1135	Soil No.	Avg. of all 8 pots	Avg. of 4 pots 31–1389	Avg. of 4 pots D 1135
H7	.050	.056	.045	M6	.093	.116	.070	H7	.090	.050	.130
O3	.046	.053	.040	M10	.074	.084	.064	H8	.089	.068	.110
M6	.041	.045	.037	H11	.070	.076	.064	M10	.088	.073	.103
K5	.035	.034	.035	H8	.070	.072	.068	M6	.079	.050	.108
H8	.031	.034	.029	K12	.068	.074	.061	H4	.062	.050	.075
W9	.030	.035	.025	W9	.067	.068	.065	K5	.061	.050	.073
M10	.030	.029	.031	H7	.063	.074	.052	O3	.059	.050	.068
H11	.030	.035	.025	H4	.059	.062	.055	H11	.059	.053	.065
H2	.030	.041	.020	K5	.056	.062	.049	K12	.059	.050	.068
K12	.029	.028	.030	H1	.047	.057	.037	W9	.055	.050	.060
H1	.023	.028	.017	O3	.021	.022	.020	H2	.049	.040	.056
H4	.020	.023	.017	H2	.020	.017	.023	H1	.042	.035	.050
Diff. needed for odds of:											
19 to 1	.006	.009	.009		.006	.009	.009		.008	.012	.012
99 to 1	.008	.012	.012		.008	.012	.012		.011	.016	.016

Nitrogen: The data in Table X (R.C.M. analyses of crusher juices) show some very significant effects of different soils upon the nitrogen content of the crusher juice of canes grown on these soils. This effect was probably not an effect of the available nitrogen content of the soil at time of planting, since there is but little evidence of any correlation between nitrogen in the soil at planting and in the juice at harvest, e.g., $r = +.21 \mp .19$; nor is it likely that it is a direct effect of the nitrogen fertilizer that was applied, since all soils were similarly supplied with nitrogen fertilizer. Thus it would seem that either some unrecognized soil component or condition has significantly influenced the nitrogen supply that was released from these soils to the plant roots, or that some deficiency or adverse factor has prevented the complete assimilation of the absorbed nitrogen within the plant.

Although the crusher juice from variety 31–1389 had a higher average nitrogen content (at .037 per cent) than D 1135 (at .029 per cent) the difference was not significant on soils Nos. H4, K5, M6, H8, M10, and K12.

Phosphate: Significant differences were also obtained from various soils upon the phosphate content of the crusher juices. However, the poor correlations ($+ .32 \mp .26$ for 31–1389, and $+ .22 \mp .28$ for D 1135) between the per cent P_2O_5 in the soil and that found in the crusher juices would indicate that some factor other than the actual amount of the soil's supply of available phosphate was operative. It must be remembered that all soils were equally and liberally supplied with superphosphate before planting; evidently the liberation of this applied phosphate to the plant roots was an inverse effect of the soils' ability to "fix" this phosphate.

Although the 31–1389 crusher juices had an average 25 per cent higher content of P_2O_5 than the D 1135, this greater concentration was not a proved effect in cane grown on soils Nos. H2, O3, H4, H8, and W9.

Potash: The dominating effect of the cane variety on the percentages of K_2O found in the crusher juices greatly overshadows the effects of soil. However, there is a significant effect of the soil on per cent K_2O of the crusher juice of both varieties—for the variety 31–1389 the correlation coefficient for K_2O in soil and in juice is $+ .50 \mp .21$; for D 1135 it is $+ .73 \mp .14$.

Conclusion:

There seems but little doubt that we have measured different effects upon cane quality, cane composition, and cane yields, which have resulted when different soils have been cropped under identical conditions. But the real causes of such different soil effects are still somewhat vague and perhaps quite complex. The finger of suspicion has, however, been pointed directly and indirectly at the nitrogen supply which the cane plant has absorbed but not assimilated. The possibility is hinted at that soil differences in the kinds, numbers, and activity of microorganisms, and the influences of soil organic matter, soil reaction and allied factors upon this soil population may hold the key we are looking for. Certainly such differences as we have observed in the effects of soils upon the quality of sugar cane add still further complexity to our attempts to segregate the factors which can influence cane quality.

Integration of Climatic and Physiologic Factors With Reference to the Production of Sugar Cane*

By Harry F. Clements†

In most crop areas of large continental land masses, the climate over one field is essentially the same as that over an adjoining field. In fact, oftentimes the weather conditions are comparatively uniform for several hundreds of miles (except for small differences due to direction of slope, et cetera). Such uniformity has led students of crop production to ignore largely all but soil influences in considering the growth of plants. Yet variations in climate from year to year cause considerable differences in behavior of a given crop. On the other hand, plant ecologists in their studies of natural vegetation have long recognized that atmospheric factors such as temperature, sunlight and rainfall in truth outweigh the influences of soil except in such isolated cases as halophytism. Since plant ecologists are interested in processes which require periods of time longer than a single growing season, it is quite reasonable to assume that their emphasis is on more fundamental factors than those used by crop men who think in terms of crop yields determined by variables imposed by them within a single season.

It is perhaps unfortunate that agriculturists have ignored the teachings of the ecologists, for it is quite clear that only a small part of the plant comes from the substance of the soil itself. This part, the mineral substances, forms to be sure a very important but nevertheless small part of the plant. Of the dry matter in a plant the overwhelming part is derived directly from the atmosphere about the plant and from water through the process of photosynthesis—a process which is paced almost wholly by temperature and light intensity, with light intensity becoming more important as the temperatures reach the optimum range.

Because of the peculiar nature of Oahu's topography, it is possible to have greater climatic variations over very short distances than could be encountered over vast distances on large land masses. Thus at Waipio the days are very bright and warm, and rainfall is so scant that irrigation is practiced. At Kailua a few miles away on the windward side of Oahu, the days appear to be cooler with fairly heavy rainfall. Actually, however, the temperature differences between the two places are insignificant, but differences in light intensity are quite large. This circumstance then offered the opportunity for this study.

Experimental

Four ¼-acre plots were selected at the Waipio and Kailua substations, respec-

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tively. Plantings were made with the sugar cane variety 31–1389. The first planting at each place was made July 28, 1938, and three other separate plantings at intervals of three months were made at each place. The crop was grown on a 22-month-cycle basis. In this paper, I shall report only on the first plantings, Plots A.

The soil at both places is of a clay type. In order to estimate the influences of the soil on the experiment, top soil from the Kailua field was taken to Waipio and there placed in 16-inch concrete pots. Similar pots were filled with top soil from the Waipio field. The pots were placed side by side under Waipio weather conditions, fertilized at the same rate as the fields and planted to 31–1389. At the end of four months there was no significant difference in the growth produced. Whatever advantage there was favored the plants growing in the Kailua soil. This was understandable because of the better physical structure of the Kailua soil. Representative plants are shown in Fig. 1.

Fig. 1. Two pots on left contain Kailua soil, the two on right, Waipio soil. All grown under Waipio weather conditions. The primary shoots of the Kailua plants are somewhat taller than those of the Waipio plants.

Phosphate and potash fertilization was the same at both places and was adequate. Two hundred pounds of P_2O_5 per acre as Ammo-Phos and 200 pounds of K_2O per acre as muriate of potash were applied at the time of planting. Nitrogen was applied in part with the phosphate and later applications were made as sulphate of ammonia. At Waipio a total of 225 pounds of N was added while at Kailua 150 pounds was the total used. The nitrogen was added at intervals, presumably as the plants needed it. Actually the smaller amount used at Kailua was relatively more than was used at Waipio considering the amount of growth made at the two places. Leaf analyses verify that at all times the Kailua plants possessed a higher nitrogen level than the Waipio plants.

The fields at Waipio are under irrigation, receiving about 100 inches of water per year. As shown by the record in Table I, rainfall at Kailua was adequate for the crop.

TABLE I

RAINFALL AT KAILUA

Month	Rainfall in inches	Month	Rainfall in inches	Month	Rainfall in inches
August, 1938	2.84*	April	12.39	December	4.52
September	1.42	May	5.43	January, 1940	9.83
October	8.07	June	4.08	February	5.79
November	2.40	July	3.74	March	4.22
December	3.04	August	2.99	April	5.87
January, 1939	13.04	September	7.01	May	20.91
February	4.55	October	17.30		
March	8.37	November	6.18		

* For the last two weeks of August only.

There was a short period in September 1938 in which the six-week-old crop showed some signs of suffering; from then until August 1939 the plants showed no signs of wilting, but during this month growth was reduced at least by one half, a reduction more than offset the following month. In other words, at no time did the crop suffer irreparable damage from a lack of water.

It is clear, then, that the crops produced at Kailua and Waipio had been subjected to similar fertilizer* and moisture conditions. It may again be pointed out that the soil conditions at Kailua were at least as good as those at Waipio and perhaps somewhat better. To bring the problem clearly into focus now, it is in order to give the results of the crop harvested at the end of the 22 months of growth. The plots were burned over and harvested according to regular field practice. Cane weights and juice analyses reported in Table II are mill records.

TABLE II

YIELD AND JUICE RECORDS AT HARVEST

	Weight per acre tons of cane	Quality ratio	Tons of sucrose per acre
Kailua	65	9.0	7.2
Waipio	134	7.2	18.6

Thus, despite comparable fertilization and moisture conditions, the Kailua crop was less than half that obtained at Waipio. The differences in yield are so enormous that an analysis of growth conditions is in order.

At the time that the plantings were made a weather station was established within the field at each place. Rainfall, humidity, sunlight and temperature records were compiled. In order to obtain the last two, a system used by the experiment station of the Pineapple Producers Cooperative Association was employed. This consists of using two Friez distant thermographs, model 1100. The "bulb" of one is painted white and placed inside a regulation weather kiosk and the "bulb" of a

* For a detailed discussion of the availability of nitrogen, phosphorus, potash, and water in these two soils, see later sections in this paper under those headings.

second instrument is painted black and placed on the outside of the kiosk so as to be fully exposed to direct sunlight. The white-bulb instrument records the air temperature while the black bulb is heated by the sun's rays and, in a very crude way, the difference between the temperatures of the black and white bulbs is a function of the intensity of the sunlight.

In order to obtain some real figure to use in evaluating the data so obtained, a planimeter is used to obtain the area under the temperature curve for a day (6 a.m.–6 p.m.) and above a base line (50° F. was used as a base). The value so obtained is then divided by the area on the chart of 1° F. for a 12-hour period. This value when added to the 50° F. base gives the real weighted air temperature for that particular day. A similar reading is obtained for the same day from the record made by the black-bulb instrument. This reading will always be higher than the air temperature reading. The difference between the two readings is here taken as a crude measure of the light intensity for that particular day and is hereafter referred to as "sunlight-degrees." Such records have been obtained for the full 22 months during which this experiment was conducted. The accumulated record from month to month is shown in Fig. 2.

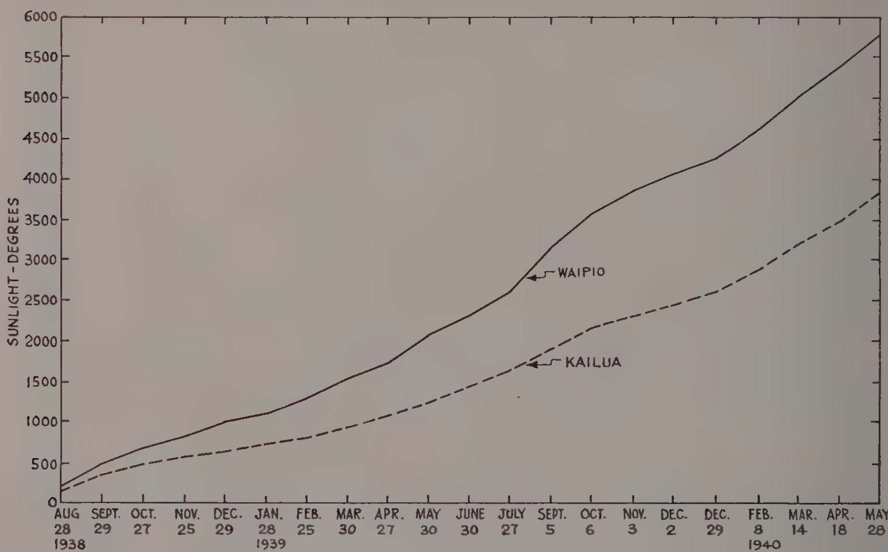

Fig. 2. Record of accumulated sunlight-degrees for Waipio and Kailua.

U. K. Das in attempting to explain the differences in yield from year to year studied temperature data for a long period of years and came to the conclusion that sugar yields could be correlated with maximum daily temperatures obtained over 70° F. Thus, for a given day if the maximum temperature was 80° F., the crop that day enjoyed 10° in excess of 70° F. These excess degrees have come to be known as "day-degrees" or "Das' day-degrees." Das found a close correlation between the yearly crop yield and the accumulated day-degrees for that year. However, in cloudy areas when the sun comes out for a very short period during a day, the temperature might rise several degrees and give a very high reading for

the day when, as a whole, the day was very poor. Although such difficulties have tended to discredit the value of the concept, it nevertheless served its purpose of focussing attention on factors other than soil in cane production. Although Das regarded his day-degrees as a record of temperature differences from day to day, actually a close comparison of the day-degrees as used by him with the sunlight-degrees and weighted temperatures obtained in this study shows that his measure was less a measure of temperature than it was a measure of light intensity. In Table III are recorded the weighted average temperatures for the full 24-hour day as well as for night (6 p.m.–6 a.m.) and for the day (6 a.m.–6 p.m.). It is clear from these series of data that there is no real difference between the 24-hour weighted temperatures at the two places (72.9° F. for Waipio, 72.4° F. for

TABLE III

AIR TEMPERATURE RECORDS

(Average per day)

	Waipio			Kailua		
Period Ending	Day T. (Avg.)	Night T. (Avg.)	Avg. T.	Day T. (Avg.)	Night T. (Avg.)	Avg. T.
Aug. 28, 1938..	80.9	71.3	76.1	77.6	72.2	74.9
Sept. 29	81.6	70.8	76.2	78.7	74.3	76.5
Oct. 27	81.0	71.2	76.1	77.4	73.3	75.3
Nov. 25	78.9	69.5	74.2	75.6	72.3	74.0
Dec. 29	76.5	69.3	72.9	73.3	70.8	72.0
Jan. 28, 1939..	75.1	67.8	71.4	72.0	69.6	70.8
Feb. 25	75.5	67.7	71.6	72.0	69.5	70.6
Mar. 30	74.9	65.8	70.4	72.3	68.5	70.4
Apr. 27	74.6	65.5	70.1	72.2	67.9	70.0
May 30	77.9	66.6	72.1	75.3	70.5	72.9
June 30	80.0	69.2	74.7	75.1	70.8	73.0
July 26	82.6	69.7	76.2	76.9	71.6	74.2
Sept. 5	81.5	70.5	75.2	77.1	72.0	75.1
Oct. 6	80.4	68.7	74.6	77.6	70.3	73.9
Nov. 3	77.6	69.7	73.7	75.4	70.6	73.0
Dec. 2	76.4	65.9	71.1	72.8	69.7	71.3
Dec. 29	75.1	65.2	69.9	72.4	67.2	69.7
Feb. 8, 1940...	73.6	64.3	68.7	72.9	66.4	69.7
Mar. 14	76.7	62.8	69.8	73.9	65.9	69.9
Apr. 18	78.3	64.6	71.5	74.7	66.5	70.6
May 28	81.5	68.3	74.9	76.3	70.4	73.5
Average	78.1	67.8	72.9	74.9	70.0	72.4

Kailua). The day temperatures at Waipio are higher than those at Kailua, but the night temperatures at Kailua are higher than those at Waipio. It seems clear that so far as plant growth is concerned, temperature conditions at Kailua and Waipio are very much the same.

In contrast to Table III, Das' day-degrees are recorded in Table IV.

TABLE IV

DAS' DAY-DEGREES FOR KAILUA AND WAIPIO

(Average per day)

Period ending	Waipio	Kailua
August 28, 1938	14.9	10.9
September 29	16.0	11.3
October 27	15.8	10.2
November 25	12.2	7.5
December 29	10.5	5.5
January 28, 1939	9.5	4.0
February 25	10.2	5.0
March 30	9.0	5.7
April 27	8.8	5.2
May 30	11.5	7.6
June 30	14.4	8.1
July 26	18.1	10.2
September 5	18.2	12.2
October 6	18.7	13.2
November 3	15.7	8.5
December 2	12.3	5.1
December 29	13.2	6.7
February 8, 1940	11.9	8.1
March 15	16.5	9.7
April 18	17.5	11.0
May 20	19.7	12.1

The accumulated day-by-day total of day-degrees for Waipio is 9374 and for Kailua 5693. Thus, with the close similarity of temperatures in mind, the day-degree measure yields a picture of something other than daily temperatures. A comparison of day-degrees with the weighted sunlight-degrees shows them to be fairly closely related. In Table V the average day-degrees and sunlight-degrees are recorded for each place as well as the ratio obtained by dividing the day-degrees by the sunlight-degrees. If these ratios were to be constant, then obviously day-degrees would be simpler to use under field practice. Such, however, is not the case. At Kailua the ratio varies from 2.87 to 1.07. At Waipio, the range is from 2.45 to 1.11. An examination of the record sheets shows that during cloudy periods the ratio is high. During clear days, the ratio is nearer unity. This, of course, is to be expected. Where the temperature curve for the day is very irregular, the maximum temperature reached is not an exact evaluation for that day; hence the day-degrees will be high. On the other hand, where the record for that day is actually a weighted daily total (sunlight-degrees), it would seem that a truer evaluation is obtained. For this reason, sunlight-degrees are used in this study as a measure of light intensity.

TABLE V

COMPARISON OF DAY–DEGREES AND SUNLIGHT–DEGREES FOR WAIPIO AND KAILUA

(Average per day)

Period ending	Waipio Sunlight–Degrees	Waipio Day–Degrees	Waipio Day–Deg. / Sunlight–Degrees	Kailua Sunlight–Degrees	Kailua Day–Degrees	Kailua Day–Deg. / Sunlight–Degrees
Aug. 28, 1938	6.8	14.9	2.19	4.9	10.9	2.22
Sept. 29	8.4	16.0	1.91	6.1	11.3	1.84
Oct. 27	7.0	15.8	2.18	5.0	10.2	2.03
Nov. 25	4.8	12.2	2.45	3.5	7.5	2.13
Dec. 29	4.6	10.5	2.27	1.9	5.5	2.87
Jan. 28, 1939	4.8	9.5	1.99	1.6	4.0	1.91
Feb. 25	6.1	10.2	1.71	3.1	5.0	1.61
Mar. 30	8.1	9.0	1.11	4.6	5.7	1.25
April 27	7.7	8.8	1.14	4.2	5.2	1.24
May 30	8.4	11.5	1.37	5.3	7.6	1.44
June 30	8.3	14.4	1.74	6.0	8.1	1.35
July 26	10.6	18.1	1.68	7.9	10.2	1.28
Sept. 5	13.1	18.2	1.39	6.4	12.2	1.89
Oct. 6	14.1	18.7	1.32	7.8	13.2	1.69
Nov. 3	9.6	15.7	1.62	5.35	8.5	1.59
Dec. 2	7.3	12.3	1.69	4.8	5.1	1.07
Dec. 29	8.3	13.2	1.59	6.2	6.7	1.09
Feb. 8, 1940	9.45	11.9	1.3	6.9	8.1	1.18
Mar. 14	10.7	16.5	1.54	8.7	9.7	1.12
April 18	9.7	17.5	1.82	8.15	11.0	1.36

Although it appears to be more logical to select a weighted measure of sunlight as a yardstick of growing conditions, it is nevertheless necessary to apply these measures to actual plant growth and determine from such a study whether the differences in sunlight can actually be correlated with the difference in growth. If the soil nutrients, moisture, and weighted temperatures at the two locations are the same, then it should be possible to calculate the growth at Kailua from the growth made at Waipio, or vice versa, by using the sunlight variable.

Growth data were taken at approximately monthly intervals, and consisted of measurements of the extension of stem, the number of leaves emerging during the period, the number of leaves dying since the previous measurement, the length and basal width as well as maximum width of each leaf. In each plot, twenty pilot plants were selected from which these records were taken from the time of germination until harvest. In this way a very complete record of the growth of the plants, rapidity of leaf emergence, and leaf fall, as well as the number of functioning leaves, was compiled. Because of the lanceolate character of the leaf blade, it is easy to estimate the area of the blade by multiplying the length of the blade by the basal width. This gives a value only slightly removed from values obtained by planimeter readings and had the obvious advantage of simplicity. Thus, by knowing the area of the leaves functioning during a given period, it was possible to calculate the total leaf area per plant for the particular period. It is apparent

that the leaf area of a crop is a very important factor, because light is absorbed mainly by the leaves and because two of the most important processes in the plant basic to growth—photosynthesis and transpiration—are also functions of leaf area. The leaf areas are reported in Table VI and shown in Fig. 3.

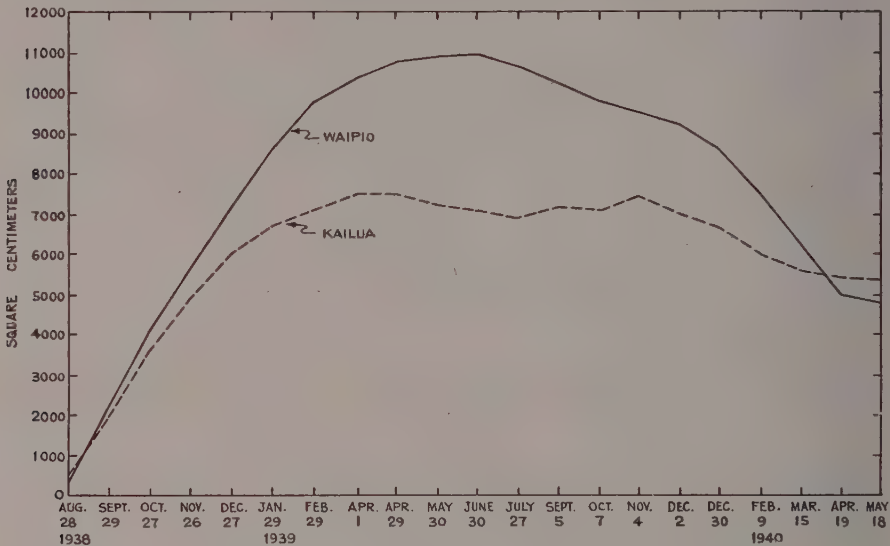

Fig. 3. Record of average leaf area per plant at Waipio and Kailua.

TABLE VI

LEAF AREA PER PLANT

(CM²)

For period ending	Kailua	Waipio	Kailua / Waipio
Aug. 28, 1938	561.0	451.5	1.24
Sept. 29	2051.2	2239.3	.91
Oct. 27	3601.7	4085.5	.88
Nov. 26	4937.9	5719.5	.86
Dec. 27	6049.0	7198.8	.84
Jan. 29, 1939	6670.0	8572.4	.78
Feb. 29	7114.7	9793.4	.73
April 1	7504.4	10412.7	.72
April 29	7557.3	10771.5	.70
June 3	7259.8	10942.7	.66
June 30	7105.9	11049.4	.64
July 27	6872.4	10675.8	.64
Sept. 5	7261.7	10222.1	.71
Oct. 7	7132.8	9807.5	.72
Nov. 4	7528.8	9451.2	.80
Dec. 2	7100.9	9208.2	.77
Dec. 30	6745.9	8612.2	.78
Feb. 9, 1940	6005.9	7448.5	.80
Mar. 15	5548.2	6171.6	.90
April 19	5451.2	5016.3	1.09
May 28	5426.0	4777.9	1.14

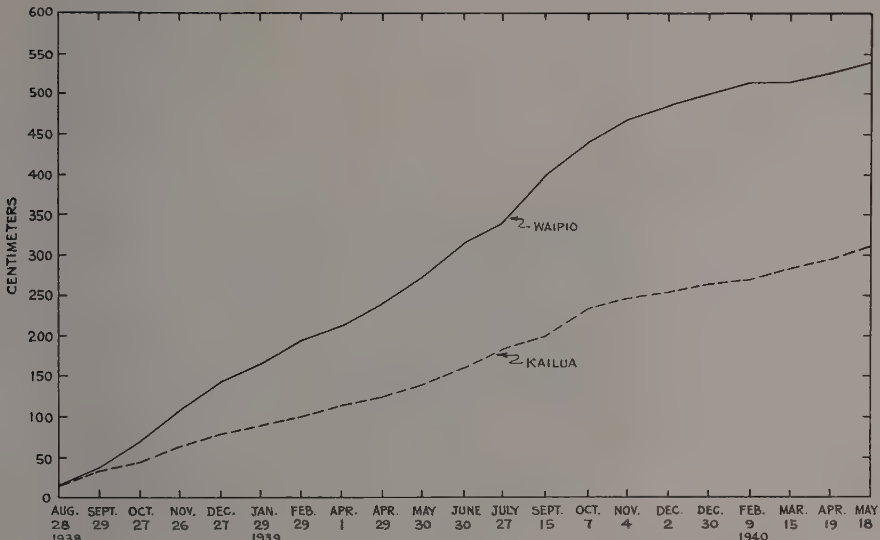

Fig. 4. Record of growth (stem extension) at Waipio and Kailua.

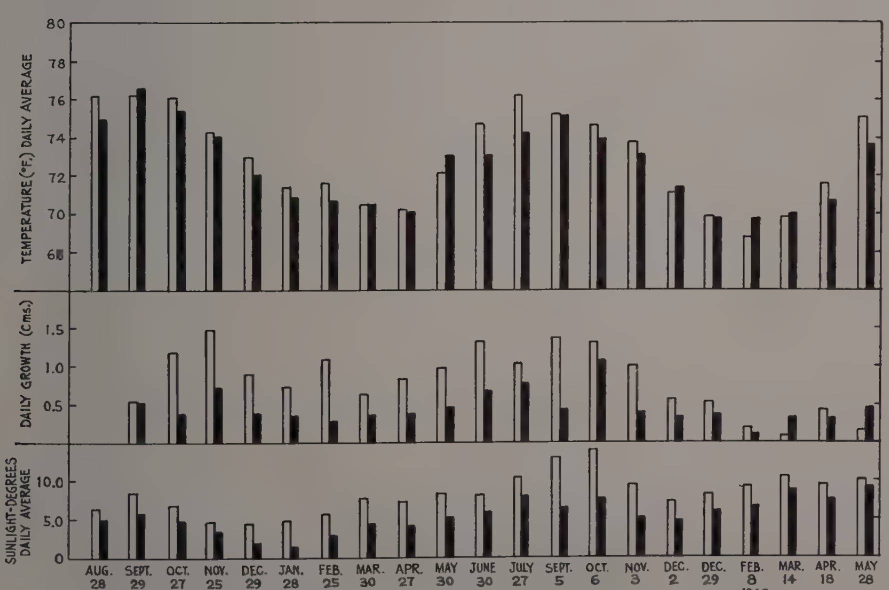

Fig. 5. Correlation of growth for Waipio and Kailua plants (center) with daily temperatures (top), and sunlight-degrees (bottom). Clear bars represent Waipio, solid bars, Kailua.

The density of the stand will also have a bearing on the amount of light absorbed per acre and so must be determined. To obtain such a value certain observation rows within each plot were set aside and the average number of plants per linear foot of row was obtained. These records are shown in Table VII.

The growth of the plants was obtained in two ways: first, by measuring the increase in length from month to month; and second, by selecting a sample each month and obtaining its green and dry weights. These dried samples will be described later. Suffice it to say here that a close correlation exists between the extension records and the actual weight records. Since the extension records were obtained from the same pilot plants throughout the growth period, the growth curve is more reliable and will be used here as the index of growth (Fig. 4).

In Fig. 5 an histogram is used to show at a glance the relations existing among air temperature, sunlight-degrees, and the average daily extension of the plants for Kailua and Waipio. Casual examination will reveal greater similarity between sunlight-degrees and extension than between air temperature and extension. Since the air temperature at Waipio is so near that at Kailua, it need not enter into the consideration here, although clearly it is an important crop factor. While there are many periods in which sunlight-degrees and growth coincide fairly well, there are others in which the fit is not too close. It should be observed that during the last four collections the disparity between sunlight-degrees and growth is very great, especially for Waipio, but this is explained on the basis of the drying-off period prior to harvest.

Other factors, however, are involved in changing sunlight-degrees into the substance of the plant. One of these factors is the leaf area of a plant and another, the density of the stand. Since the crop does not close in sufficiently to be competitive until about the sixth month, the densities are considered from that time on and are reported in Table VII. From these data it appears that the Kailua stand became stabilized at 80 per cent of the Waipio stand.

TABLE VII

DENSITY OF STAND

Period ending	No. of stalks per linear foot of row — At Kailua	No. of stalks per linear foot of row — At Waipio	$\frac{\text{Kailua}}{\text{Waipio}}$
Feb. 22, 1939	3.75	3.76	1.00
April 1	3.35	3.45	.97
April 28	3.05	3.41	.89
June 3	2.93	3.42	.85
June 30	2.94	3.48	.84
July 27	3.02	3.48	.86
Sept. 5	2.85	3.48	.82
Oct. 7	2.85	3.46	.82
Nov. 4	2.77	3.46	.80
Dec. 2	2.77	3.46	.80

Now with these various factors, we should be in a position to calculate what the Kailua growth should have been basing the calculation on the growth actually made at Waipio. To effect this estimate, the daily stem extension increment at Waipio is multiplied by the ratio of leaf areas and the ratio of light intensities and divided by the ratio of crop densities. In other words:

$$G_K = \frac{G_W \times A \times L}{D} \quad \text{where } G_K = \text{growth increment at Kailua}$$

G_W = growth increment at Waipio

A = ratio of leaf areas $\left(\frac{\text{Kailua}}{\text{Waipio}}\right)$

L = ratio of light intensities $\left(\frac{\text{Kailua}}{\text{Waipio}}\right)$

D = ratio of densities $\left(\frac{\text{Kailua}}{\text{Waipio}}\right)$

These data are presented in Table VIII. The last column gives the calculated growth rate for Kailua. It is now in order to compare the calculated growth rate with the observed. Two comparisons may be made. One is on a month-by-month basis. This, however, is not satisfactory and the reason seems to be that if a plant fails to reach its maximum rate of growth for one month, it appears to make up for it the next. Conversely, if a plant outdoes itself one month, it slows down the next. This is borne out by facts of the following nature: in late July and August, 1939, the Kailua plants suffered from drought and grew a daily average of 0.46 cm. According to calculations, however, they should have grown 0.59 cm. In the following month the calculated growth rate was 0.63 cm. per day, but the observed was 1.08 cm. The result is that over short periods a plant may not grow but stores up its food and, when the particular obstacle is removed, it makes up for the deficiency by growing faster than normal because it can draw on the reserve set aside during adversity. This is clearly shown in studies of the carbohydrate metabolism to be discussed later.

The second method of comparison is to allow the accumulation of the monthly increments so that such irregularities as those just discussed will be smoothed out. This is done in Table IX.

In Table VIII, the values for the various periods are summarized.

TABLE VIII

CALCULATION OF KAILUA GROWTH

Period ending	Daily dewlap increment at Waipio (cm.) (G_W)	Light Intensity K/W (L)	Leaf area K/W (A)	Density K/W (D)	$\frac{L.A.}{D}$	$\frac{L.A.}{D} G_W$ (G_K)
Aug. 28, 1938....	....	.721	1.24	1.00	.894	...
Sept. 29	.55	.726	.91	1.00	.661	.43
Oct. 27	1.21	.714	.88	1.00	.628	.76
Nov. 25	1.48	.73	.86	1.00	.628	.93
Dec. 29	.90	.413	.84	1.00	.347	.31
Jan. 28, 1939....	.77	.333	.78	1.00	.259	.20
Feb. 25	1.09	.508	.73	1.00	.371	.40
Mar. 30	.66	.568	.72	.97	.422	.28
April 27	.85	.546	.70	.89	.429	.36
May 30	.98	.631	.66	.85	.490	.48
June 30	1.36	.723	.64	.84	.550	.75
July 27	1.05	.745	.64	.86	.554	.58
Sept. 5	1.39	.489	.71	.82	.423	.59
Oct. 6	1.34	.553	.72	.80	.498	.67
Nov. 3	1.03	.562	.80	.80	.562	.58
Dec. 2	.59	.657	.77	.80	.634	.37
Dec. 29	.54	.747	.78	.80	.729	.39
Feb. 8, 1940....	.21	.726	.80	.80	.726	.16
Mar. 14	.08	.813	.90	.80	.915	.07
April 18	.46	.845	1.09	.80	1.15	.54

TABLE IX

CALCULATED VERSUS OBSERVED GROWTH AT KAILUA

Period ending	Calculated Kailua growth $\left(\frac{L.A.}{D} G_W\right)$ (daily) cm.	No. of days in period	Calculated growth per period	Calculated accumulated growth	Observed accumulated growth
Sept. 29, 1938.......	.43	62	26.7	26.7	33.5
Oct. 27	.76	28	21.3	48.0	44.3
Nov. 25	.93	29	27.0	75.0	65.7
Dec. 29	.31	33	10.2	85.2	79.7
Jan. 28, 1939.......	.20	30	6.0	91.2	91.1
Feb. 25	.40	28	11.2	102.4	99.4
Mar. 30	.28	33	9.2	111.6	113.5
April 27	.36	28	10.1	121.7	124.4
May 30............	.48	33	15.8	137.5	141.7
June 30	.75	31	23.3	160.8	160.6
July 27	.58	27	15.7	176.5	182.4
Sept. 5	.59	40	23.6	200.1	200.8
Oct. 6	.67	31	20.8	220.9	235.4
Nov. 3	.58	28	16.2	237.1	247.2
Dec. 2	.37	29	10.7	247.8	257.2
Dec. 29	.39	27	10.5	258.3	267.5
Feb. 8, 1940.......	.16	40	6.4	264.7	272.0
Mar. 14	.07	35	2.5	267.2	284.2
April 18	.54	35	18.9	286.1	295.7

A comparison of the calculated versus observed growth of the plants at Kailua emphasizes the closeness of fit. During the first few months, there was a departure from observed growth, but it is to be remembered that during this period the plants suffered in their growth because of a lack of rainfall. After this period, however, there was an unusually close agreement between calculated and observed growth until October 1939. Following this period, the calculated growth is slightly below the observed. A reason for this is apparent since the Waipio plants on which the calculations are based were subjected to the drying-off process during the last six months, but despite all these difficulties, the final calculated growth is less than 4 per cent below the observed (Fig. 6).

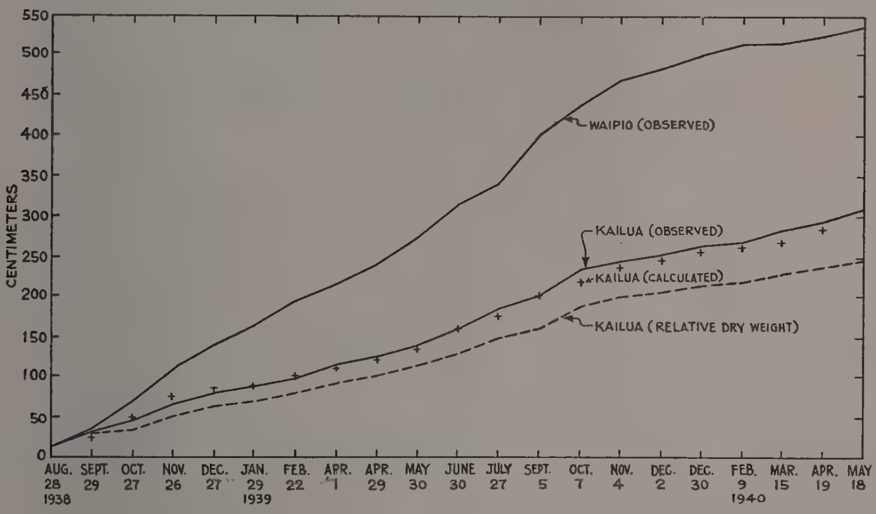

Fig. 6. Calculated versus observed growth for Waipio and Kailua plants. Two solid lines represent observed growth. X points represent calculated growth for Kailua plants. Short-dash line represents the same calculations but without factor for density. This line is very close to the observed ratio between the dry weights of the Waipio and Kailua plants.

It would seem, then, that the differences in growth at Waipio and Kailua are explainable largely on the basis of sunlight intensity. To be sure, it is possible that the differences in leaf area and plant density may have been due to factors other than light intensity. One function commonly ascribed to phosphorus is that it encourages stooling. In some plants, the failure to stool properly is used as a symptom denoting phosphorus deficiency. In this case, however, the association of the lower crop density at Kailua with a somewhat lower phosphorus content of the tissues hardly seems correct (see later section on phosphorus). To begin with, the density of the stand at Kailua was much greater during the early months than was finally maintained. In other words, abundant stooling occurred but when overcrowding developed competition resulted in a rapid decrease in the number of survivors. At Waipio the same phenomenon occurred. This elimination of shoots seems more logically related to light conditions than to a possible phosphate deficiency.

To summarize the problem so far, plants grown at Kailua and at Waipio under similar fertilization, moisture, and temperature conditions gave markedly different

yields. This disparity in yields is explainable on the basis of three factors, all of which are related to sunlight or its absorption: (1) sunlight intensity itself, to which growth of sugar cane in the presence of sufficient water is directly related; (2) leaf area, to which the absorption of sunlight and, therefore, growth is also directly related; and (3) the density of the stand, to which the absorption of sunlight per plant per acre is inversely related.

Curiously enough, if the factor for density is not included in the calculation (Fig. 6), the resulting growth curve of Kailua is in very close agreement with the dry weight of the Kailua plants as compared with the Waipio dry weights. Thus, assuming that the dry weights of the Waipio plants follow the same general trend as their length, then the calculations used above but without the factor for density give a final ratio between the two crops of .471 while the observed ratio is .473.

Clearly, then, under conditions of adequate soil moisture and mineral nutrients, the magnitude of a crop in any given year or in any given locality is determined not by soil conditions but the atmosphere about the plant, particularly temperature and sunlight intensity. Undoubtedly, too, the length of day contributes another factor, but here in the tropics where so little difference exists between summer and winter, this factor is of much less importance than in areas approaching the poles.

To state the problem in other terms, the variations in yield from year to year may in large part be attributable to the differences in sunlight and temperature, or atmospheric energy. Further, it is possible to evaluate the sunlight intensity and to calculate values for crop production by using comparatively simple instruments.

Since it appears that the tonnage of any given crop is so largely affected by atmospheric conditions, it is clearly a corollary that the fertilizer requirements of a crop will be influenced materially by them. This will be particularly true of nitrogen. Since one year varies from another and one area varies from another, any empirical application of fertilizer to a crop is of value only to that area for that particular season. It would seem that a system should be devised where the plant to be produced is followed in its growth in the field in which it is to be grown. If an index could be found of the plant's general state of well-being, this would reflect the plant's reaction to the weather and so a more reasonable fertilization program could be followed.

In an effort to devise such a system in addition to the growth records compiled, samples of plants were removed from the field approximately each month beginning in February 1939. Five plants representative of the major stand were selected at each place. These plants were cut at the junction with the original seed piece. Collections were always made early in the morning between 6:00 and 7:30 A.M. These samples were taken to the laboratory and separated into several samples. The millable cane was cut into sections of three internodes beginning at the bottom of the cane and continuing upward to the point where leaves were still attached. The top green-leaf portion of the plant is, of course, the active aerial part; hence it should contain the tissues which can be used as an index of the plant's well-being. Therefore, this top section was separated into several samples. The youngest leaf—the one just emerging from the terminal cluster—was called leaf No. 1 and the leaves were numbered downward. The bottom leaves on the cane up to and including leaf No. 7 are removed and separated into sheaths and blades. The stem, to which these leaves are attached, is cut off below the node

of leaf No. 6. This portion of the stem is referred to as the green-leaf cane. The sheaths associated with this cane are referred to as the green-leaf sheaths, and the blades, the green-leaf blades.

Leaves 6, 5, 4, and 3 are next removed. The stem associated with them is cut off below the node carrying leaf No. 2 and, since it is the region of rapid elongation, is referred to as the elongating cane. Leaves 6, 5, 4, and 3 are separated into sheaths and blades and are referred to as elongating sheaths and elongating blades, respectively.

The remaining material includes the meristematic tip of the stem as well as the meristematic leaf bases and the spindle leaf, leaf No. 1 and also leaf No. 2. Five inches of the bottom of this material are cut off and are called the meristematic material, and the remaining portion is called the spindle cluster.

After separating the plants into these various portions, each portion is weighed, then sliced into small pieces, dried in a blast oven, weighed again, ground in a Wiley mill and stored for analysis. From these two weighings the amount of water in each tissue is determined.

Analysis of the tissues included determinations of phosphorus, potassium, nitrogen and the carbohydrate fractions, reducing sugars, sucrose and acid-hydrolyzable materials, and finally moisture. I shall now proceed with the presentation and discussion of these results.

Phosphorus:

Although all of the portions of the several collections were analyzed for phosphorus, it is not cogent at this time to present all of these data. Thomas* of Pennsylvania State College has developed a system of diagnosis of a plant's N–P–K requirements based on the analysis of leaves taken from the plant under consideration. In order, therefore, to conserve space, I shall present the data obtained for leaves Nos. 3, 4, 5, and 6 for the various collections. These results are shown in Table X.

TABLE X

PHOSPHORUS CONTENT OF YOUNG LEAVES

P_2O_5—% DRY WEIGHT

Date of sampling	Waipio	Kailua
1939		
February 15	0.366	0.268
March 23	.277	.259
April 20	.304	.229
May 25	.291	.277
June 26	.268	.224
July 22	.362	.238
September 1	.330	.195
September 29	.268	.252
October 27	.316	.252
November 25	.339	.268
December 26	.344	.247
1940		
February 1	.304	.277
March 8	.238	.238
April 13	.211	.211
Average	0.301	0.245

* Foliar Diagnosis: Principles and Practice, Plant Physiology, 12:571–599. 1937.

The data of Table X are shown graphically in Fig. 7. It is clear that the general phosphorus level at Waipio was maintained at a uniformly high level. During the months of intense growth (June, July, August, September and October), the

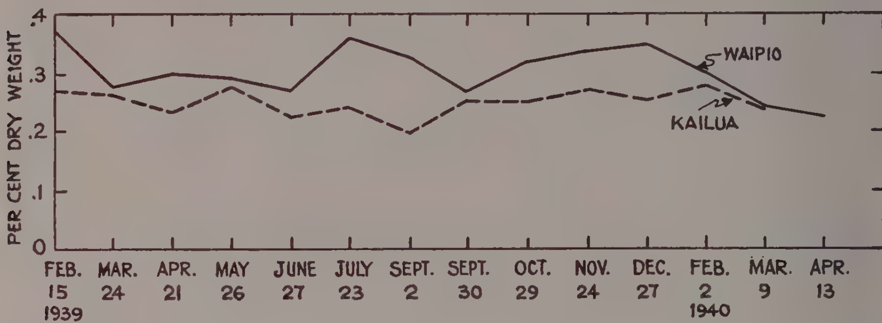

Fig. 7. Phosphorus index for Waipio and Kailua plants (P_2O_5 content of young leaf blades).

quantity of phosphorus in the leaves was for the most part above the average of 0.301. This means, of course, that the phosphorus-providing ability of the soil was excellent. It is possible that the above-average yield of phosphorus during these months was correlated with the higher soil temperature. The somewhat below-average P_2O_5 content during the early months is probably correlated with lower soil temperatures, for it must be remembered that the plants were growing slowly during this period; hence the actual amount of phosphorus removed during this period would be considerably less than that required during the months of rapid growth. It is clear from the analysis of the remainder of the plant parts that actually phosphorus is excessive in the Waipio soil. There is even a strong accumulation in the old cane.

The phosphorus curve for Kailua is at a lower level than that for Waipio. It is doubtful, however, whether it was ever a limiting factor in growth. Three reasons may be given for this statement:

(1) First, at Waipio, trials conducted for a quarter of a century show that with no addition of phosphate, the yield of cane has been maintained year after year. On April 23, 1940, a collection of plant material was made from plots which throughout this period had received only nitrogen as well as from some which had received a complete fertilizer. The plants collected were about a year old and were the variety 31–1389. The P_2O_5 content of the young leaves (N plot) was 0.239 per cent (dry weight) and of the old leaves 0.181 per cent. The average P_2O_5 content of the corresponding leaves of the plants grown at Kailua was 0.245 per cent and 0.186 per cent, respectively. In other words, the Kailua plants maintained in their leaves the same level of phosphorus as was maintained by plants growing under Waipio conditions.

(2) The second reason for believing the phosphorus at Kailua was not a limiting factor is based on the preliminary experiment in which Kailua soil was taken to Waipio and planted with cane. The plants growing in the Kailua soil at Waipio were at least as good as those growing in the Waipio soil at Waipio, particularly with reference to the number of suckers produced.

(3) The third reason is based on the analysis of the Kailua leaves themselves. During May, June, July—three months of good growth—the phosphorus content was maintained at approximately average. August with its drought saw a marked decrease in growth and also the lowest phosphate level. During September, with good rains, the growth rate was the greatest obtained for the entire cycle, yet the phosphorus composition during this period rose sharply and was maintained thereafter.

For all these reasons it seems reasonable to assume that the Kailua plants did not suffer from a lack of phosphorus and, on the other hand, that the Waipio plants were experiencing an excess of it.

Potassium:

Potassium analyses were made of all the fractions of the plant, but again only the composition of the young leaves (elongating blades) will be reported here (Table XI).

TABLE XI

POTASSIUM CONTENT OF YOUNG LEAVES

K_2O—% Dry Weight

Date	Waipio	Kailua
1939		
February 15	1.89	1.83
March 24	1.63	1.96
April 21	1.60	1.96
May 26	1.46	1.38
June 27	1.70	1.78
July 23	1.43	2.14
September 2	1.17	1.88
September 30	1.35	1.83
October 29	1.41	1.75
November 24	1.65	2.02
December 27	1.48	1.90
1940		
February 2	1.52	2.16
March 9	1.67	2.03
Average	1.54	1.89

These data are also shown in Fig. 8. The potassium level for Kailua with two exceptions is considerably above the Waipio curve. Yet experience tells us that the plants at Waipio are receiving an adequate supply. The plots, which for a long period of years have received no potash, have equalled the performance of those that have received it. It seems clear that both the Waipio and Kailua plants were consuming more potash than was actually required for maximum activity. The potash problem will be presented in greater detail elsewhere, but it suffices here to observe that potassium was not a limiting factor in these studies.

Nitrogen:

The nitrogen problem is a totally different problem. Abundant evidence has accumulated showing that excessive amounts of nitrogen will cause succulence and

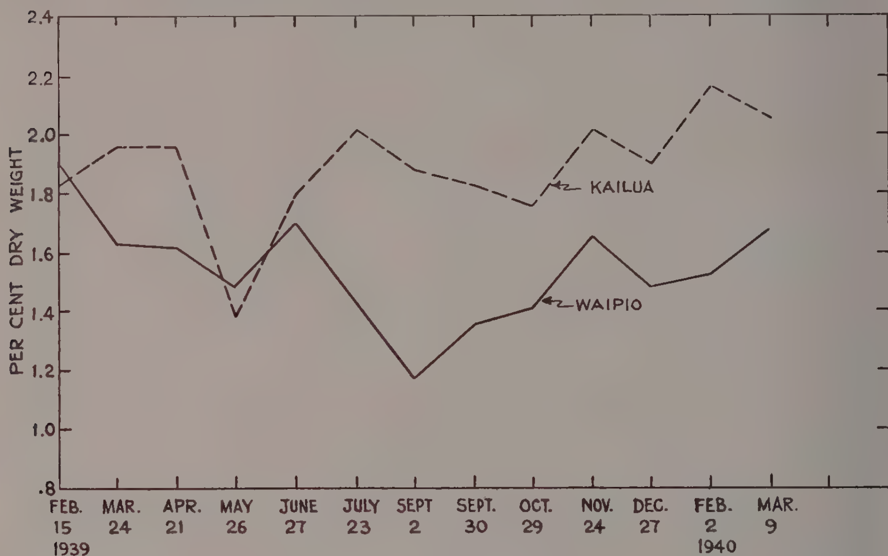

Fig. 8. Potassium index for Waipio and Kailua plants (K_2O content of young leaf blades).

a failure to accumulate reserve carbohydrates. It seems from the present studies that nitrogen is not nearly so important in determining the total carbon assimilated as some have maintained. Rather, the total carbon assimilated by a plant is determined by the atmospheric conditions of temperature and light intensity about the plant (provided, of course, that salts and moisture are not limiting) and no matter how much nitrogen is added in excess of the optimum, the total carbon assimilated will not be materially altered, although some evidence indicates that nitrogen may cause a mild stimulation of the photosynthetic process. In other words the quantity of substance produced per unit area and time is much more a function of the atmosphere, and in this, nitrogen or any other mineral material is of little moment unless limiting. This statement, of course, does not apply to shade-loving plants, or plants incapable of taking advantage of maximum atmospheric energy.

The problem of excesses of mineral materials has been given some attention by investigators. By some, excesses of potassium and phosphorus have been labelled as luxury consumption with apparently little effect on the quality of the plant involved. But it has long been recognized that excesses of nitrogen usually result in the production of large cells with thin cell walls in which very little carbohydrates accumulate. This is readily appreciated when it is remembered that the plant absorbs inorganic nitrogen from the soil and, by consuming carbohydrates, converts this inorganic nitrogen into organic nitrogen. Thus, if excessive amounts of nitrogen are assimilated, comparatively less carbohydrates remain for storage or cell wall construction. Conversely, if nitrogen is limiting, the carbohydrate material accumulates and growth is reduced.

It is obvious, then, that the application of nitrogen must be made to parallel assimilation of carbon, which in turn is determined by atmospheric conditions. In other words nitrogen must be applied in accordance with atmospheric conditions. Farm observations have shown this repeatedly. During cloudy seasons, the quality of sugar cane is poor unless the nitrogen added is below normal requirements. On the other hand, in exceptionally bright seasons such as we have just enjoyed, the same amount of nitrogen that produced a poor quality crop in dull years produces an exceptional crop this year.

Some means must be devised whereby it will be possible to integrate the amounts of nitrogen required with the weather which the plant is experiencing in order to obtain the maximum quality of crop and at the same time not sacrifice tonnage. This is particularly important with sugar cane where the only interest lies in the production of the maximum tonnage of sucrose per acre. With excessive nitrogen, more and more of this sucrose is irretrievably converted into cellulosic products. On the other hand, if nitrogen is limiting or less than optimum, one loses in the amount of storage tissue produced.

Because of the great significance of providing the proper amount of nitrogen to fit the amount of carbohydrates produced, the results of the nitrogen and carbohydrate analyses are presented in some detail. The nitrogen values are estimates of the total nitrogen for the several parts of the plant. The data for Waipio are presented in Table XII and those for Kailua are in Table XIII.

Before proceeding with a discussion of the nitrogen content of the various tissues of the plants, it would probably be worth while to average the nitrogen percentages of the plant tissues at the two places in order to obtain a better idea of the levels involved. These averages for the season of each tissue are given in Table XIV.

In view of the averages obtained, it is certain that the upper green parts of the Kailua plants had fully as much or more nitrogen as the Waipio plants. That the Kailua plants really had more than they needed is indicated by the nitrogen in the cane itself: first, the actual percentage of nitrogen in the cane is between two and three times that of the Waipio plants and, second, there is no gradient in the nitrogen content of the Kailua plant cane as there is in the Waipio cane. Thus the nitrogen content of the green-leaf cane at Waipio averages 0.34 per cent while the first internodes average 0.14 per cent with more or less a steady decrease from top to bottom. The Kailua plants, on the other hand, range from 0.48 per cent to 0.44 per cent. In general, if a plant is suffering from a shortage of an element, it will move this element from old mature portions to the young, growing portions. This might suggest that the Waipio plants could have used more nitrogen than was available to them. However, the yield of 134 tons per acre of a good quality-ratio crop (7.2) suggests that the Waipio crop was very near to optimum and that the Kailua crop in reality had more nitrogen than it needed

TABLE XII

TOTAL NITROGEN CONTENT OF WAIPIO PLANTS
(AS N — % DRY WEIGHT)

Plant part	Feb. 13 1939	Mar. 23	Apr. 20	May 25	June 26	July 22	Sept. 1	Sept. 29	Oct. 27	Nov. 25	Dec. 27	Feb. 1 1940	Mar. 8	Apr. 12
Meristem	3.70	3.06	3.09	2.79	2.96	2.79	2.57	2.35	3.22	3.04	2.46	2.90	2.06	2.63
Spindle cluster	1.23	1.06	1.14	.96	1.09	.99	.91	.94	1.02	1.05	.89	.91	.78	.85
Elongating blades	1.24	1.28	1.16	1.06	1.12	1.13	1.06	.92	1.03	1.07	1.01	.87	.95	.89
Green-leaf blades	.96	1.04	.94	.90	.77	.84	.76	.72	.76	.76	.75	.85	.76	.69
Elongating sheaths	.49	.45	.43	.39	.42	.37	.37	.37	.45	.45	.37	.38	.35	.33
Green-leaf sheaths	.35	.37	.34	.29	.27	.29	.30	.27	.29	.29	.31	.33	.36	.30
Elongating cane	1.26	1.13	1.12	1.46	1.12	1.25	1.25	1.16	1.36	1.16	1.04	1.39	1.10	1.35
Green-leaf cane	.39	.35	.39	.37	.32	.32	.32	.39	.30	.37	.33	.26	.34	.26
Top internodes	.22	.25	.27	.24	.23	.23	.18	.19	.25	.31	.33	.32	.32	.27
15th 3 internodes	....	....	....	....	....	....	....	....	....	....	....	....	....	.22
14th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	.22	.18
13th 3 "	....	....	....	....	....	....	....	....	....	....	.29	.25	.22	.16
12th 3 "	....	....	....	....	....	....	....	....	....	.25	.24	.21	.20	.17
11th 3 "	....	....	....	....	....	....	....	....	....	.25	.21	.16	.17	.14
10th 3 "	....	....	....	....	....	....	....	....	.17	.18	.19	.15	.18	.13
9th 3 "	....	....	....	....	....	....	....	.19	.14	.23	.17	.14	.18	.12
8th 3 "	....	....	....	....	....	....	.17	.16	.13	.16	.12	.14	.15	.13
7th 3 "	....	....	....	....	....	.24	.17	.15	.13	.14	.12	.13	.14	.14
6th 3 "	....	....	....	....	.23	.24	.14	.14	.15	.14	.12	.12	.14	.13
5th 3 "	....	....	....	.22	.24	.21	.20	.17	.14	.14	.12	.13	.13	.13
4th 3 "	....	....	.23	.19	.18	.18	.17	.15	.13	.13	.10	.11	.12	.12
3rd 3 "	....	.23	.19	.17	.19	.15	.19	.11	.10	.09	.10	.11	.12	.12
2nd 3 "	.18	.19	.15	.15	.16	.14	.12	.10	.09	.08	.08	.10	.11	.12
1st 3 "	.17	.19	.19	.17	.17	.15	.11	.09	.09	.11	.12	.11	.11	.13

TABLE XIII

TOTAL NITROGEN CONTENT OF KAILUA PLANTS
(AS N — % DRY WEIGHT)

Plant part	Feb. 15 1939	Mar. 24	Apr. 21	May 26	June 27	July 23	Sept. 2	Sept. 30	Oct. 28	Nov. 24	Dec. 27	Feb. 2 1940	Mar. 9	Apr. 13
Meristem	2.91	2.51	2.13	2.22	2.60	2.65	1.23	2.86	2.10	3.06	2.48	2.76	3.14	2.92
Spindle cluster	.95	1.11	1.13	.98	.94	.93	.78	1.00	1.00	1.03	.92	.99	1.00	.94
Elongating blades	1.30	1.27	1.24	1.16	1.08	1.04	1.01	1.08	1.09	1.25	1.12	1.12	1.18	1.06
Green-leaf blades	1.05	.98	1.03	.98	.94	.99	.75	.91	.98	.98	.98	.98	.96	.88
Elongating sheaths	.43	.48	.42	.40	.38	.38	.32	.41	.42	.48	.38	.48	.73	.40
Green-leaf sheaths	.38	.38	.38	.33	.34	.31	.29	.35	.31	.35	.33	.37	.36	.34
Elongating cane	1.21	1.25	.95	1.13	1.27	1.21	.62	1.34	.94	1.50	1.47	1.62	1.34	1.20
Green-leaf cane	.51	.53	.60	.46	.43	.43	.34	.39	.44	.44	.39	.69	.51	.52
Top internodes	.53	.46	.66	.48	.35	.38	.47	.50	.34	.39	.27	.43	.48	.43
14th 3 internodes	....	....	....	....	....	....	....	....	....	....	....	....	....	.51
13th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	....	.43
12th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	.49	.37
11th 3 "	....	....	....	....	....	....	....	....	....	....	....	.41	.42	.45
10th 3 "	....	....	....	....	....	....	....	....	....	....	....	.39	.35	.34
9th 3 "	....	....	....	....	....	....	....	....	....	.37	.39	.40	.38	.35
8th 3 "	....	....	....	....	....	....	....	....	.41	.37	.37	.44	.39	.34
7th 3 "	....	....	....	....	....	....	....	.43	.44	.36	.37	.44	.41	.35
6th 3 "	....	....	....	....	.42	.43	.50	.42	.46	.38	.39	.43	.42	.32
5th 3 "	....	....	....	....	.50	.46	.50	.44	.48	.34	.38	.39	.43	.31
4th 3 "	....	....	....	.50	.50	.52	.49	.45	.50	.37	.38	.37	.38	.29
3rd 3 "	....	....	.59	.51	.46	.43	.48	.40	.46	.32	.35	.34	.33	.27
2nd 3 "	....	.42	.59	.47	.39	.36	.45	.36	.38	.32	.33	.30	.31	.28
1st 3 "	.64	.48	.57	.47	.38	.39	.47	.38	.36	.28	.33	.30	.32	.33

TABLE XIV

AVERAGE NITROGEN CONTENT OF TISSUES

(N — % Dry Weight)

Plant part	Waipio	Kailua
Meristem	2.83	2.54
Spindle cluster	.99	.98
Elongating blades	1.06	1.15
Green-leaf blades	.82	.96
Elongating sheaths	.40	.44
Green-leaf sheaths	.33	.34
Elongating cane	1.22	1.22
Green-leaf cane	.34	.48
Top internodes	.26	.44
15th 3 internodes	.22	
14th 3 internodes	.20	.51
13th 3 internodes	.23	.43
12th 3 internodes	.21	.43
11th 3 internodes	.19	.43
10th 3 internodes	.17	.36
9th 3 internodes	.15	.38
8th 3 internodes	.15	.39
7th 3 internodes	.15	.40
6th 3 internodes	.15	.42
5th 3 internodes	.16	.42
4th 3 internodes	.15	.44
3rd 3 internodes	.15	.41
2nd 3 internodes	.13	.40
1st 3 internodes	.14	.44

The fact that the nitrogen content of the Kailua cane is higher than the Waipio cane may in part be accounted for by the shorter internodes. The nodes made up of active tissue form a relatively larger part of one section than in the Waipio plants but this accounts for a comparatively small amount of the difference.

In examining Tables XII and XIII, it is evident that each plant part has a fairly characteristic nitrogen content. Thus the meristem is highest, followed by the elongating cane, the elongating blades, the spindle cluster, and the green-leaf blades. The sheaths are nearly as low in nitrogen as the millable cane itself.

To select a tissue to use as an index of the nitrogen level in the plant, one must look for a tissue whose nitrogen content is high and at the same time one which reflects the levels studied. Of the three most active tissues—the meristem, the elongating cane, the elongating blades—the last named is the only one which is sufficiently precise and at the same time actually does reflect the difference in general nitrogen metabolism. Furthermore it is easily accessible.

To further narrow the study, then, the nitrogen content of these young leaves for Kailua and Waipio are shown in Fig. 9. The trend in general for plants is to maintain a higher nitrogen level during the younger stages than at later stages unless the nitrogen applied is excessive. The Waipio plants show that nitrogen was not excessive. The rise in nitrogen from May through July indicates an ample supply during stages of rapid growth. The decrease in nitrogen from July 22 to September 29 shows that during the period of excessive growth, the soil was not

providing nitrogen at a rapid enough pace to maintain the level of nitrogen in the leaves. By the end of October, because of decreased atmospheric energy, growth had slowed down and the nitrogen level increased because of failure of utilization.

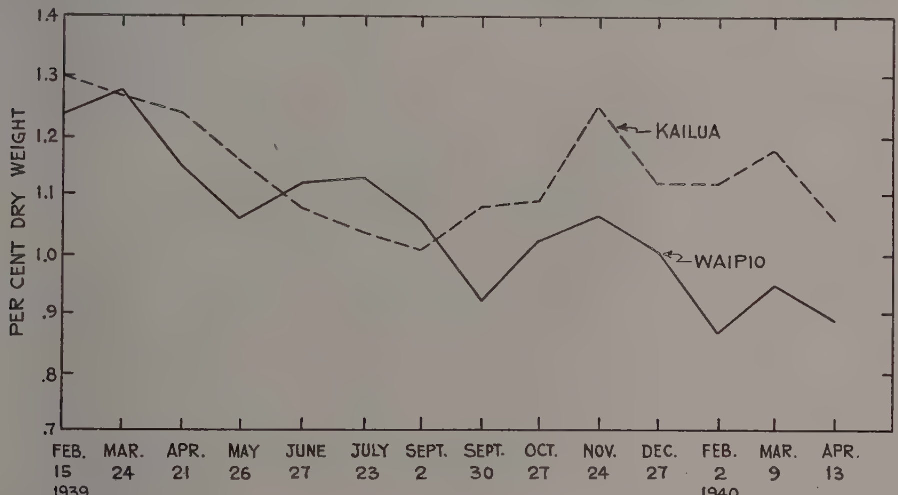

Fig. 9. Nitrogen index for Waipio and Kailua plants (total N content of young leaf blades).

This increase continued until the plants were forced into semi-dormancy by the drying-off period which began late in November.

The Kailua curve for nitrogen lends itself equally well to understanding when other growth conditions are referred to. During the period from February 15 to June 26, there was in general a similarity in level at Kailua and Waipio. The decrease from June 26 to September 1 is correlated with the drought which developed and which materially reduced growth during August. It is clear in this instance that the nitrogen was not limiting in the soil even though the level in the plant was at its lowest, because during the month of September with no further addition of nitrogen but with a good rainfall, the plants made the greatest growth of their entire cycle, in fact approaching the best growth even for Waipio, and yet during this period the nitrogen level rose. Then, as the atmospheric energy was reduced, the growth rate decreased and nitrogen continued to accumulate. Thus the nitrogen content of the Kailua plants was materially higher in the end of the cycle than in the Waipio plants. The reader should be reminded that the quality ratio of the Kailua plants was 9.0 while that for Waipio was 7.2.

Now, despite all the importance that some have attached to the nitrogen level as an index of plant growth, it is obvious from the study so far that nitrogen is of little importance in determining the quantity of crop produced, provided, of course, that it is not actually a limiting factor. The higher nitrogen level of the Kailua plants was of no moment so far as the final yield was concerned. (The Kailua crop yield was 65 tons per acre, the Waipio yield 134 tons per acre.) This difference in yield is, in large part, explainable on the basis of the differences in atmospheric energy available to the crop. The level of nitrogen, however, will have a strong influence on the quality of the crop produced, but even here the level of

nitrogen by itself is of little more than suggestive value. Fig. 9 shows clearly that available moisture as well as season has a marked effect on the level of nitrogen. It appears, then, that since the amount of carbohydrate produced is in general a function of atmospheric energy available, an estimate of the carbohydrate metabolism is of even greater importance than the nitrogen metabolism since the latter is very largely dependent upon the former. It, therefore, develops that two internal factors—carbohydrates produced and the moisture level—are of equal, perhaps greater significance in determining the quality of the crop produced. We shall now proceed with a study of the carbohydrate metabolism.

The three forms of carbohydrates of importance to sugar cane are the reducing sugars, sucrose, and a complex referred to as acid-hydrolyzable carbohydrates. A discussion of this last group will be deferred at this time. The first two forms will be considered. All the samples collected were analyzed for the three fractions of carbohydrates, but for the sake of brevity, the reducing sugars and sucrose will be combined and referred to as total sugars. The total sugars for the various parts are reported in Tables XV and XVI.

Examination of the total sugar content of the cane itself shows that, in general, the Kailua plants have at least as much and usually more sugar per gram of dry material than the Waipio plants. This point is of much interest and merits a far more detailed study. Actually the reducing sugars in the Kailua cane are very low and the sucrose relatively higher than in the Waipio plants. Thus the millable cane of Kailua plants has between 0.3 per cent and 1.5 per cent (dry weight) reducing sugars while the range of the Waipio cane is from 4.0–11.5 per cent in the upper internodes and as high as 15 per cent and 16 per cent in the lower internodes. It seems, too, that sucrose which is once laid down in the green-leaf cane is not easily obtainable for growth purposes although it is clear that sucrose is lost from the bottom of the cane and apparently is not replaced. The portion of the cane from which sugar is lost is indicated in Table XV.

The reducing sugars and sucrose in the green tops, however, seem to form a readily interconvertible system and hence can be considered as the combined total sugars. These sugars are being used by the plant in building new tissues, leaves, stems and roots. If the sugars are being formed more rapidly than tissues are being formed, there should be an accumulation of sugars in some part other than the mature stem. If the tissues are being formed more rapidly, however, the sugar level of the temporary storage organ should drop. Where to find this index tissue is a comparatively simple problem. The rapidly elongating cane should be the place since sugars must traverse this tissue before reaching the stem tip and it is also the region in which new cane stem is being produced. An examination of this tissue in Tables XV and XVI shows that, with one or two exceptions explainable later, the Kailua plants are consistently lower in total sugars than their Waipio counterparts. The elongating cane tissue is not very satisfactory, however, as an index tissue since its size varies greatly from month to month. An index tissue should be fairly constant in size from month to month. A search for such

TABLE XV

TOTAL SUGAR CONTENT OF WAIPIO PLANTS

(% DRY WEIGHT)

Plant part	Feb. 13 1939	Mar. 23	Apr. 20	May 25	June 26	July 22	Sept. 1	Sept. 29	Oct. 27	Nov. 25	Dec. 26	Feb. 1 1940	Mar. 8	Apr. 12	May 18
Meristem	6.4	10.2	8.1	10.7	8.7	16.4	9.8	9.8	10.0	9.1	12.4	11.8	18.3	10.6	10.6
Spindle cluster	5.9	6.4	6.5	6.5	3.5	6.0	6.2	6.0	5.1	4.9	5.5	5.4	6.2	6.2	6.1
Elongating blades	3.2	3.0	3.0	3.1	2.3	2.2	2.0	2.8	2.4	2.6	2.3	3.1	3.2	3.7	3.9
Green-leaf blades	2.9	2.9	3.2	3.9	2.4	2.9	2.3	2.3	2.2	2.2	2.0	2.6	3.6	4.0	5.5
Elongating sheaths	10.0	12.0	9.8	13.5	10.7	12.9	11.5	14.9	9.9	9.0	10.5	12.5	14.9	17.6	19.9
Green-leaf sheaths	6.1	6.2	6.3	9.55	5.1	6.9	7.9	6.7	5.3	4.2	5.3	8.3	11.1	13.6	18.1
Elongating cane	21.4	25.2	23.5	22.9	24.0	20.5	22.1	24.0	20.0	22.0	27.5	21.6	25.7	23.8	18.6
Green-leaf cane	41.4	37.8	35.3	38.9	42.6	40.0	38.7	37.7	40.1	36.1	48.2	49.7	47.8	43.5	39.0
Top internodes	51.2	48.4	50.6	59.2	58.0	56.1	53.0	48.7	51.2	47.2	55.1	54.2	52.1	53.6	45.8
17th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	48.7
16th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	....	....	60.2
15th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	....	56.0	56.4
14th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	61.0	57.9	58.0
13th 3 "	....	....	....	....	....	....	....	....	....	....	54.3	50.0	54.8	58.4	55.9
12th 3 "	....	....	....	....	....	....	....	....	....	53.5	55.0	47.4	57.9	53.9	53.9
11th 3 "	....	....	....	....	....	....	....	....	....	51.3	52.7	55.1	55.5	56.6	50.4
10th 3 "	....	....	....	....	....	....	....	....	54.1	54.5	54.4	54.0	58.0	55.3	52.9
9th 3 "	....	....	....	....	....	....	....	....	56.7	50.0	54.4	51.2	57.0	50.4	52.4
8th 3 "	....	....	....	....	....	....	55.1	55.1	56.9	56.7	53.4	49.9	56.0	59.2	52.3
7th 3 "	....	....	....	....	....	54.1	58.4	52.7	49.6	49.9	51.8	51.8	50.4	55.1	58.1
6th 3 "	....	....	....	....	56.0	54.1	58.4	52.7	52.4	42.2	52.5	47.1	54.2	60.4	52.2
5th 3 "	....	....	....	58.6	56.4	55.2	51.4	53.8	52.0	47.6	43.5	42.6	52.6	46.5	45.4
4th 3 "	....	....	54.2	61.1	58.0	53.7	58.1	44.6	41.2	41.6	48.6	35.2	43.0	40.8	44.0
3rd 3 "	....	55.1	56.6	64.1	53.4	41.1	55.5	47.6	40.8	37.3	43.2	33.1	39.2	43.8	40.1
2nd 3 "	57.5	53.4	56.3	58.9	55.2	45.8	36.0	36.8	29.1	35.7	45.3	32.2	38.8	39.3	34.5
1st 3 "	54.8	47.1	47.6	55.1	50.6	33.7	43.4	32.6	30.8	38.2	35.7	30.3	34.9	36.5	34.5

TABLE XVI

TOTAL SUGAR CONTENT OF KAILUA PLANTS

(% DRY WEIGHT)

Plant part	Feb. 15 1939	Mar. 24	Apr. 21	May 26	June 27	July 23	Sept. 2	Sept. 30	Oct. 29	Nov. 25	Dec. 27	Feb. 2 1940	Mar. 9	Apr. 13	May 19
Meristem	8.8	5.7	10.7	11.8	9.6	10.7	19.4	8.8	14.1	7.0	11.1	10.6	6.1	10.0	9.4
Spindle cluster	5.8	4.5	5.5	3.5	4.2	4.5	6.8	3.4	5.9	4.2	3.3	5.2	5.9	4.0	4.3
Elongating blades	2.5	2.9	3.4	3.0	2.5	2.6	3.3	1.4	1.9	1.5	2.6	2.9	3.2	4.7	3.0
Green-leaf blades	3.2	2.4	3.2	3.4	4.3	3.3	4.5	2.4	1.5	2.5	2.4	2.6	3.9	4.8	3.5
Elongating sheaths	8.1	8.2	9.2	10.6	10.9	11.6	13.2	10.0	7.9	7.1	8.6	13.9	13.1	9.9	12.2
Green-leaf sheaths	5.5	5.2	5.8	6.0	10.0	7.4	8.8	6.2	4.4	3.3	4.0	8.5	12.5	9.5	8.3
Elongating cane	19.6	19.1	28.1	22.5	18.5	20.1	33.7	18.9	21.4	13.0	16.4	12.4	13.4	19.7	18.4
Green-leaf cane	44.5	40.6	45.9	38.6	37.5	40.2	54.7	42.8	41.9	46.6	40.7	40.8	45.5	37.9	33.0
Top Internodes	56.6	54.2	53.7	54.8	52.0	50.9	58.0	51.7	56.7	56.4	60.2	61.8	58.1	58.6	42.8
14th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	....	54.0	51.3
13th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	....	58.6	55.3
12th 3 "	....	....	....	....	....	....	....	....	....	....	....	....	60.4	63.8	57.5
11th 3 "	....	....	....	....	....	....	....	....	....	....	....	59.3	60.8	58.2	62.2
10th 3 "	....	....	....	....	....	....	....	....	....	....	....	61.3	59.4	63.2	64.5
9th 3 "	....	....	....	....	....	....	....	....	....	57.7	57.8	63.9	58.6	51.1	62.3
8th 3 "	....	....	....	....	....	....	....	....	61.4	53.0	60.5	57.7	62.8	60.3	59.2
7th 3 "	....	....	....	....	....	....	....	59.4	60.7	56.3	62.0	58.5	59.1	57.2	61.8
6th 3 "	....	....	....	....	56.4	60.3	60.5	57.9	59.2	54.6	56.9	56.4	54.8	57.2	57.4
5th 3 "	....	....	....	....	58.3	59.7	57.4	60.8	59.9	55.6	54.3	54.0	51.6	56.8	51.6
4th 3 "	....	....	....	55.4	56.1	58.0	61.2	59.9	56.5	55.2	55.3	50.1	55.0	53.8	43.2
3rd 3 "	....	....	58.1	56.2	60.4	59.8	59.2	55.6	54.4	52.2	56.3	46.7	53.0	53.0	47.8
2nd 3 "	....	56.4	57.4	58.7	56.4	60.7	56.9	54.8	55.8	44.4	51.8	42.0	45.4	46.7	44.3
1st 3 "	55.3	54.7	51.1	49.5	57.6	59.4	52.7	46.4	48.9	36.1	45.4	38.4	43.9	27.7	31.8

a tissue was made and, for many reasons, the sheaths associated with the elongating cane were selected. They are comparatively uniform from month to month, their moisture content varies only slightly and they represent a precise organ.

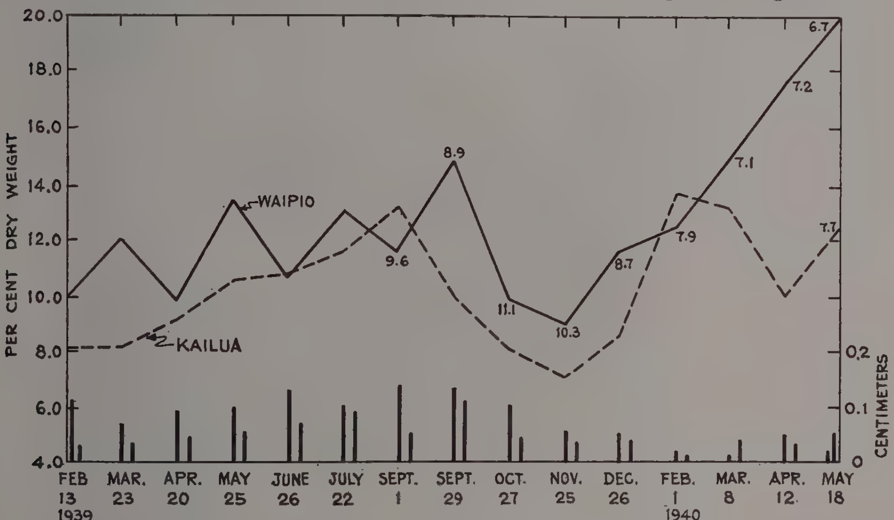

Fig. 10. Total sugar index (primary index) for Waipio and Kailua plants (total sugar content of young leaf sheaths). Numbers inserted on curves are the quality ratios of cane juice collected at indicated times. Bars at bottom refer to the average growth of the plants for the indicated periods. Bars on left of each pair represent Waipio plants; those on right, Kailua plants.

The total sugar contents of these sheaths for the Kailua and Waipio plants are shown in Fig. 10. Before discussing these, it should be pointed out again that the carbohydrate level in the plant at any one time is the difference between carbohydrate production and utilization. If the plant is growing very rapidly, thereby using up its carbohydrates faster than it is producing them, obviously the general level will drop. On the other hand if the plant is building carbohydrates faster than it is using them, the level will rise. The level, then, whatever it is, is the result of a balance between the synthetic machinery including the various essential materials, as well as atmospheric energy, and the growth mechanisms including other essential materials as well as temperature.

With this in mind it should be possible to read the history of the Waipio and Kailua crops from the carbohydrate graphs in Fig. 10. For convenience the average daily growth is plotted at the bottom of the graph. In general the Waipio plants exceeded their Kailua counterparts in carbohydrate accumulation. From February 13 to September 29 the Waipio plants show an upward trend in their carbohydrate level. From studies of other plots, it is clear that they could have been encouraged to greater activity with more nitrogen during this period, but it appears that they were fairly close to optimum for as soon as October and November came with their reduced illumination, growth continued but at the expense of temporary storage reserves. By December the crop was being dried off, growth was slowed down both by lower temperatures and low soil moisture, and

the carbohydrates began to accumulate. The accumulation was continuous and rapid until harvest.

A similar study of the Kailua plants can be made. In February and March the atmospheric energy was so low that, even with the small growth made, the carbohydrate level of the Waipio plants could not be reached. As the season advanced into summer with its higher illumination and temperature, growth increased as the level rose until September 1 when the level was at its highest while growth dropped sharply. This reduced growth was the direct result of a drought. During this drought carbohydrates were still being built but used only sparingly; hence the level reached a high point. But with heavy rains conditions were favorable for the rapid growth of September. Some of this growth was accomplished on sugars which had been stored; hence the level drops rapidly and continues to drop until low temperatures reduce growth to points below the plant's ability to use sugars. The sugar level rises until March when atmospheric conditions become such that the growth is resumed.

This index, then, can be used to follow the plant's general state of happiness. It is clear that many factors contribute to this condition, but the levels of such things as potassium, phosphorus, and the other elements can be determined by analyzing the young leaves. Thus, moisture, nitrogen, and atmospheric energy are the most important variables affecting the plant's growth and, therefore, its carbohydrate level. To indicate that the levels shown in Fig. 10 represent the real state of affairs in the plant, I have placed over the Waipio curve the quality ratios of cane cut from the Waipio plots on each date, starting when the plants were one year old. About a hundred pounds of cane were selected each time, the juice was extracted by the Cuban mill, and analyzed. On September 1 the quality ratio was 9.6. By the end of the month, the level rose and the quality ratio dropped. By October and November, the levels were very low and the quality ratio rose to 11.1 and 10.3 respectively. After this, with a steady increase in level, there was a continual improvement in the quality of juice produced. This same juice analysis was not made for the Kailua plants, but the final quality ratio by Cuban mill was 7.7.

It seems reasonable, then, that some index of the carbohydrate level of the plant is absolutely essential to integrating the effects of weather on the plant toward the end of producing a balanced plant. By watching this index, it is possible to maintain maximum growth and quality for the particular atmospheric conditions. It would seem as a result of the study of the two plots herein reported that, during the first fifteen months of growth, the sugar level of the sheaths should be maintained at ten per cent or preferably somewhat below. This can be done by adding nitrogen and keeping water available. Should the season be cloudy, however, it is clear that the level will drop very low and both nitrogen and water should be reduced. During excessively bright seasons, nitrogen and water should be increased. Beginning with the sixteenth month, the index is particularly useful. If it is well above 10 per cent at this time with the winter or spring season coming on, it is clear that irrigation can be tapered off gradually in the hope of gaining some extra growth. If the index is at 10 per cent or below, irrigation should be stopped at once for it is clear that more growth has already been obtained than was justified by weather conditions. If, on the other hand, harvest comes in

summer or early fall, by carefully watching the index the excellent growing condition may actually be used to add growth until two or at most three months before harvest when drying off the cane can be started.

Moisture:

The moisture level of a plant has a good deal to do with the type of growth which will result. The sheaths of the elongating leaves seem to be a fairly sensitive index of the balance between atmospheric energy and soil moisture. Obviously, during cloudy periods, there will be less demand for water than during bright periods. Where irrigation is practiced, the moisture level of the crop can

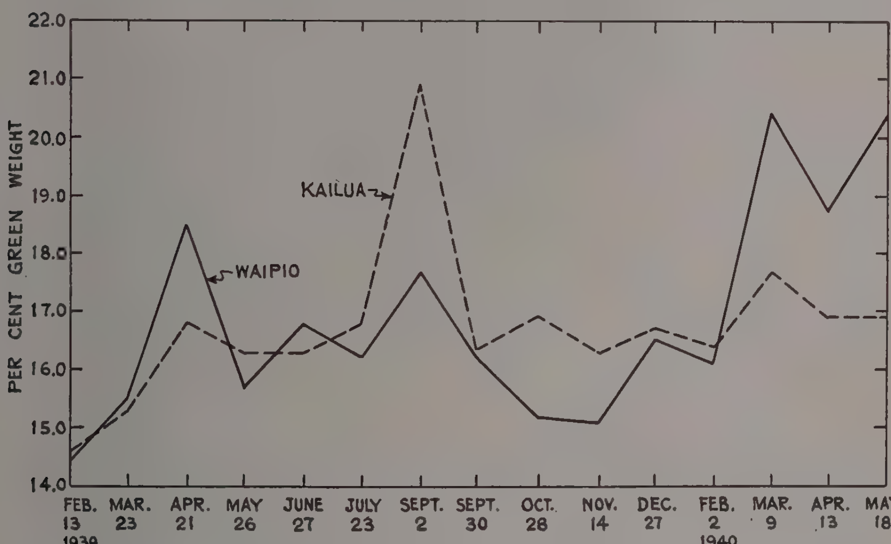

Fig. 11. Moisture index for Waipio and Kailua plants (expressed inversely as the total dry-matter content of the young sheaths).

be nicely maintained. In Fig. 11 the dry weights of the sheaths associated with the elongating leaf blades are plotted. The dry weight is, of course, in inverse relationship to the moisture content. At the early stage of a crop, the dry weight of a sheath is low. In both Kailua and Waipio plants there is a strong tendency for the dry-weight level to center around 16.5 per cent during the active growing period. The Kailua plants were particularly close to this figure except for two months—one in August, ending September 2 at the end of the drought period when the dry weight climbed to 20.9 per cent, and the other a mild departure in March 1940, following a period of low rainfall. The Waipio plants apparently suffered for a lack of moisture during April 1939, and again a mild shortage ending September 2. During the periods ending October 28 and November 14, however, more water was used than was necessary. This probably accounts for the bad drop in carbohydrates shown in Fig. 10. When the drying-off period started, of course the curve rises to very high levels. One difficulty obtains in this study with respect to the moisture levels. Collections of sample material should

have been made just prior to irrigation, or at least at some definite period relative to irrigation. This was not done and, as a result, the dry-weight curve for Waipio is very rough.

General Discussion

It is clear from general considerations that the harvested crop is the result of the many factors which operated during the time required to produce the crop. It is, therefore, equally clear that any effort to control the crop, which has as its sole criterion the final yield, must of necessity fail because it continually solves the problems of past seasons. To be of any value to the current crop, control must be based on running indices of fundamental processes and factors. That such indices are comparatively simple has been shown in this study.

The amount of atmospheric energy (sunlight and temperature) is perhaps the single most important factor in the quantity of crop produced when lesser factors are not limiting. The most direct index of this factor is the production of carbohydrate material. In part, this is measured by the total growth produced, but this in itself is of little importance to the grower. He is interested in obtaining maximum utilization of the carbohydrate produced. Hence by following the index (per cent total sugars in the young sheaths), he will know that, where these sugars accumulate, he is losing growth or, where the level is low, he is producing more growth than quality can allow; but where the level is maintained at about 10 per cent (dry weight) during the first sixteen months of growth, he has realized maximum growth concomitant with high quality under the particular weather conditions. After sixteen months, the level should rise to assure a high-quality crop at harvest. The next problem which arises is what can be done if the level is high? Obviously a high level is caused by utilization falling behind manufacture. Such a situation may develop as a result of one or more of several circumstances: low temperature, low moisture, or a deficiency of any of the three major soil elements, N, P, or K. The last two elements are least likely to cause a sudden reduction in growth and may be checked against by analysis. Temperature can be checked, and the moisture and nitrogen levels can also be checked by simple procedures.

If the level of carbohydrate is low, it means in general that utilization exceeds production. The causes of such a condition are cloudy weather associated with high temperatures, excessive moisture, and excessive nitrogen. The only control possible under such circumstances is decreased moisture. One cannot remove nitrogen from the soil but, if irrigation is practiced, the absorption of nitrogen can be materially reduced by reducing the addition of water.

A record of a field may be kept similar to those shown in Figs. 12 and 13 showing moisture levels of crop, sugar and nitrogen levels. In this way the grower knows exactly the status of his crop while he can still manipulate the several factors in order to produce high quality. It is not necessary for him to keep a record of growth of an ordinary crop, for it is clear that if the index is maintained at normal figures, he is getting all the growth possible.

The total sugar index should be maintained near to 10 per cent of the dry weight during the first sixteen months. After this the index should rise well above

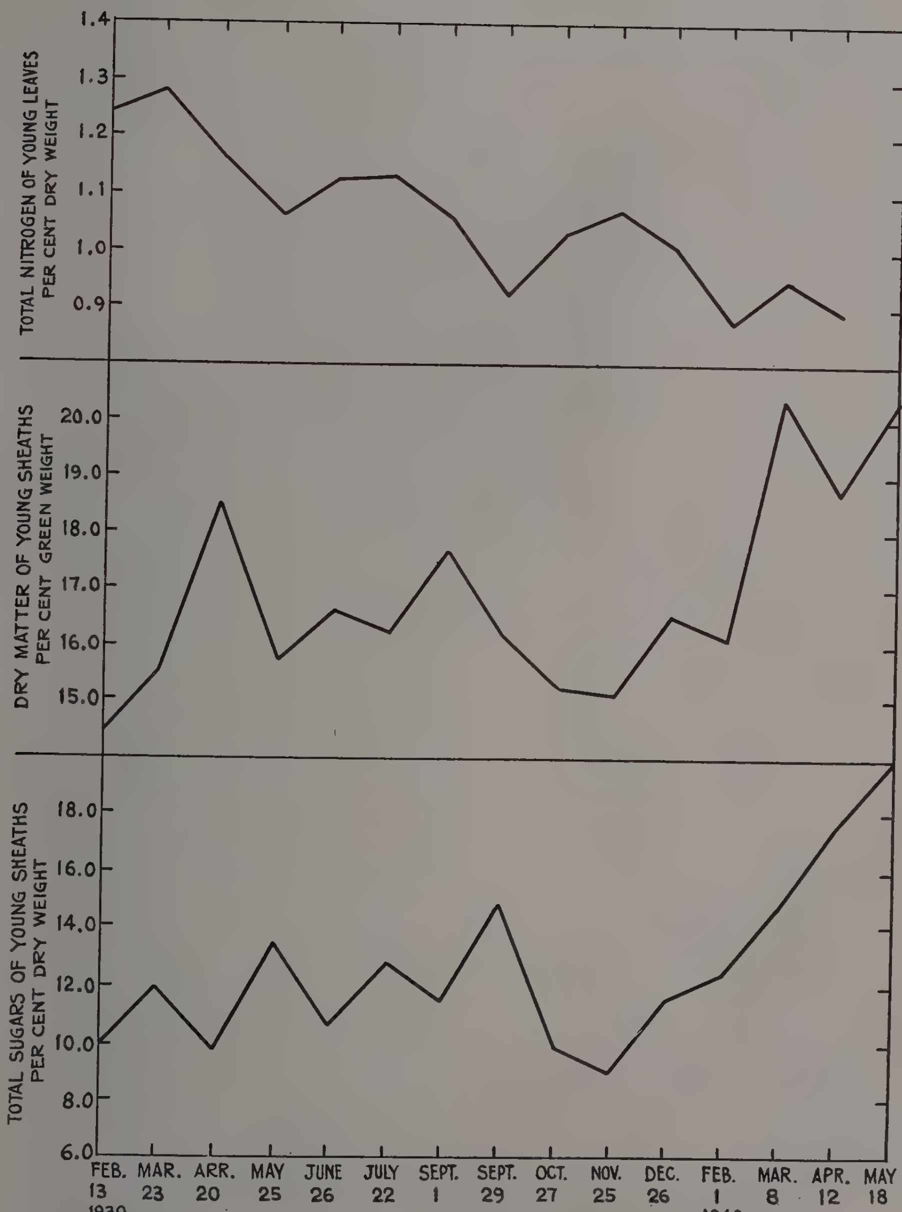

Fig. 12. Field record of the three working indices for Waipio plants: total sugars (bottom), dry matter (inverse of moisture) (center), and total nitrogen (top).

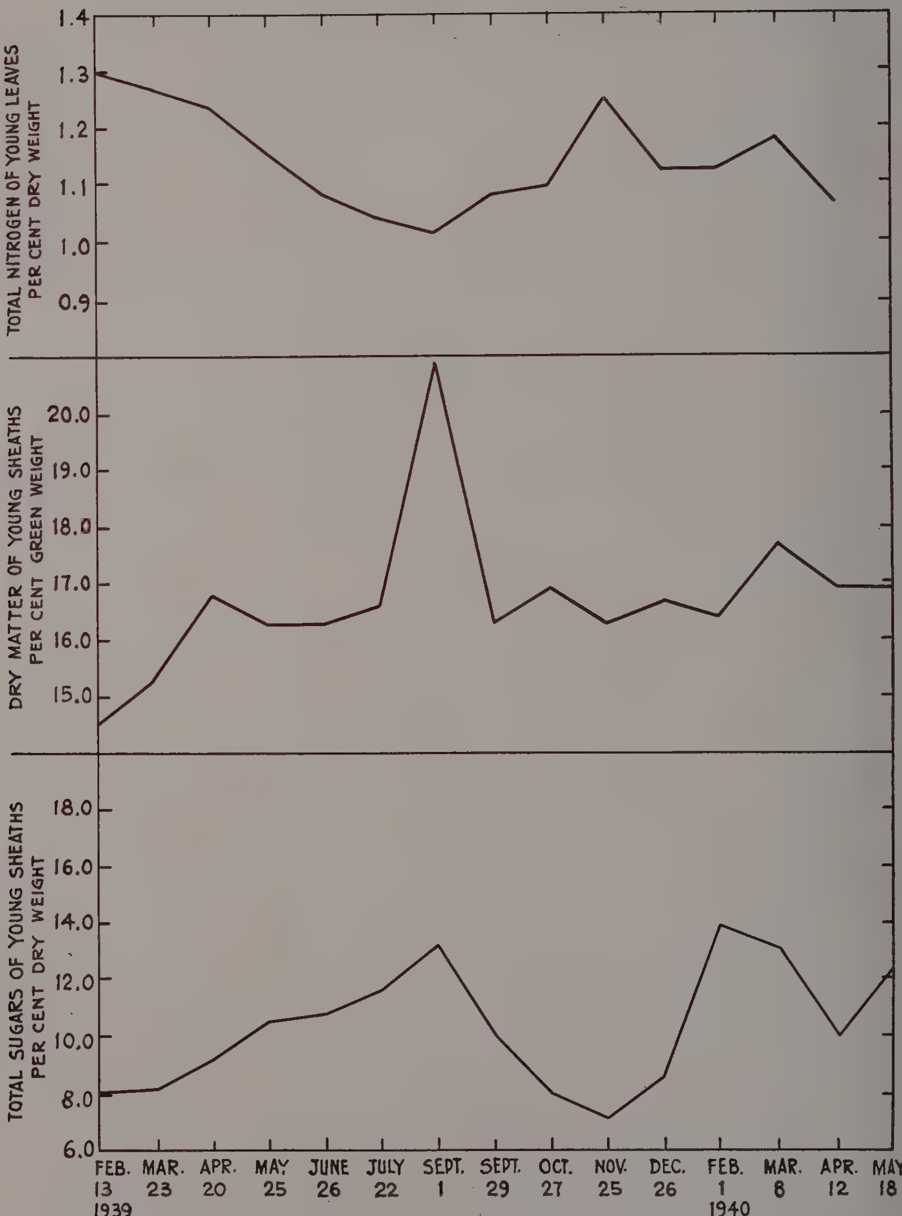

Fig. 13. Field record of three working indices for Kailua plants: total sugars (bottom), dry matter (inverse of moisture) (center), and total nitrogen (top).

15 per cent. This, then, is the primary index. If the index rises above these figures, then the dry-matter index, nitrogen index and temperatures should be consulted for causes. If the index drops well below these figures, again the three indices mentioned, in addition to the sunlight index, should be consulted. Corrective measures can be applied accordingly.

Summary

1. An attempt is made to correlate the growth of sugar cane with external and internal factors. One-quarter acre plots of variety 31–1389 were grown at Waipio and Kailua, respectively, for this purpose.

2. Complete weather and compositional records were compiled.

3. The marked difference in yield at the two places is explained on the basis of differences in sunlight intensity.

4. The growth at Kailua was calculated by means of a formula involving growth at Waipio and the ratios of leaf areas, crop densities and sunlight intensities. The calculated growth was very close to the observed growth.

5. It is demonstrated that, since climatic factors so markedly affect growth, the fertilizer requirement of a given crop is determined largely by them.

6. Because of the complexity of the problem, an attempt was made to establish indices within the plant which could be followed while the crop is still in growth, thereby facilitating the application of corrective measures before the growth cycle is complete.

7. Indices are suggested as follows: The primary index is the total sugar content of the young leaf sheaths. If growth is below normal for the particular conditions of atmospheric energy, this index will rise; if above normal, the index will fall. In either event, the following secondary indices may be consulted for causes:

(1) Moisture level—Determined as the dry weight of the young leaf sheaths (per cent green weight), and therefore expressed inversely.

(2) Nitrogen level—Determined as the percentage composition (dry weight) of the young leaf blades.

(3) Levels of other soil materials, such as phosphorus and potassium, may also be followed through analysis of the young leaves.

8. Corrective measures for the various abnormalities of the primary index are suggested.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 18, 1940 TO JUNE 11, 1940

Date	Per pound	Per ton	Remarks
Mar. 18, 1940	2.80¢	$56.00	Philippines, Puerto Ricos.
" 19	2.805	56.10	Philippines, 2.80; Cubas, 2.81.
" 26	2.80	56.00	Philippines.
" 29	2.81	56.20	Cubas.
" 30	2.80	56.00	Puerto Ricos.
Apr. 2	2.79	55.80	Cubas.
" 3	2.77	55.40	Puerto Ricos.
" 5	2.80	56.00	Philippines.
" 10	2.825	56.50	Philippines, 2.83; Puerto Ricos, 2.82.
" 11	2.85	57.00	Puerto Ricos.
" 12	2.87	57.40	Philippines.
" 16	2.95	59.00	Puerto Ricos.
" 17	2.90	58.00	Philippines, Puerto Ricos.
" 22	2.88	57.60	Puerto Ricos.
" 24	2.85	57.00	Puerto Ricos, Cubas.
May 1	2.81	56.20	Puerto Ricos.
" 2	2.80	56.00	Philippines.
" 13	2.95	59.00	Philippines.
" 14	2.90	58.00	Philippines.
" 15	2.875	57.50	Philippines, 2.90; Puerto Ricos, 2.85.
" 17	2.80	56.00	Cubas.
" 20	2.78	55.60	Puerto Ricos.
" 23	2.67	53.40	Puerto Ricos, 2.64; Cubas, 2.70.
June 4	2.70	54.00	Puerto Ricos, Philippines.
" 7	2.67	53.40	Philippines.
" 10	2.68	53.60	Philippines.
" 11	2.69	53.80	Philippines, 2.68, 2.70.

THE HAWAIIAN PLANTERS' RECORD

EXPERIMENT STATION STAFF

TABLE OF CONTENTS